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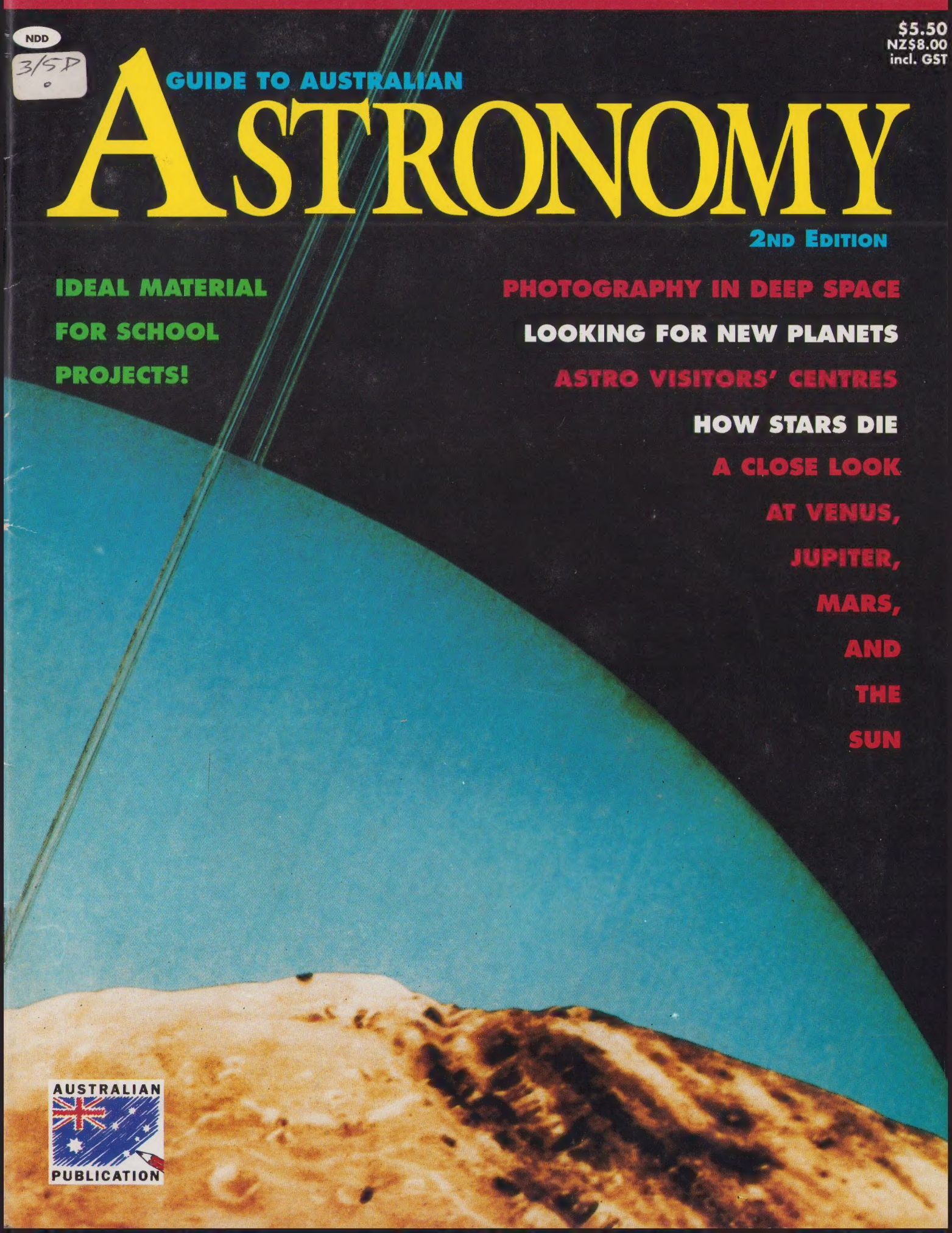

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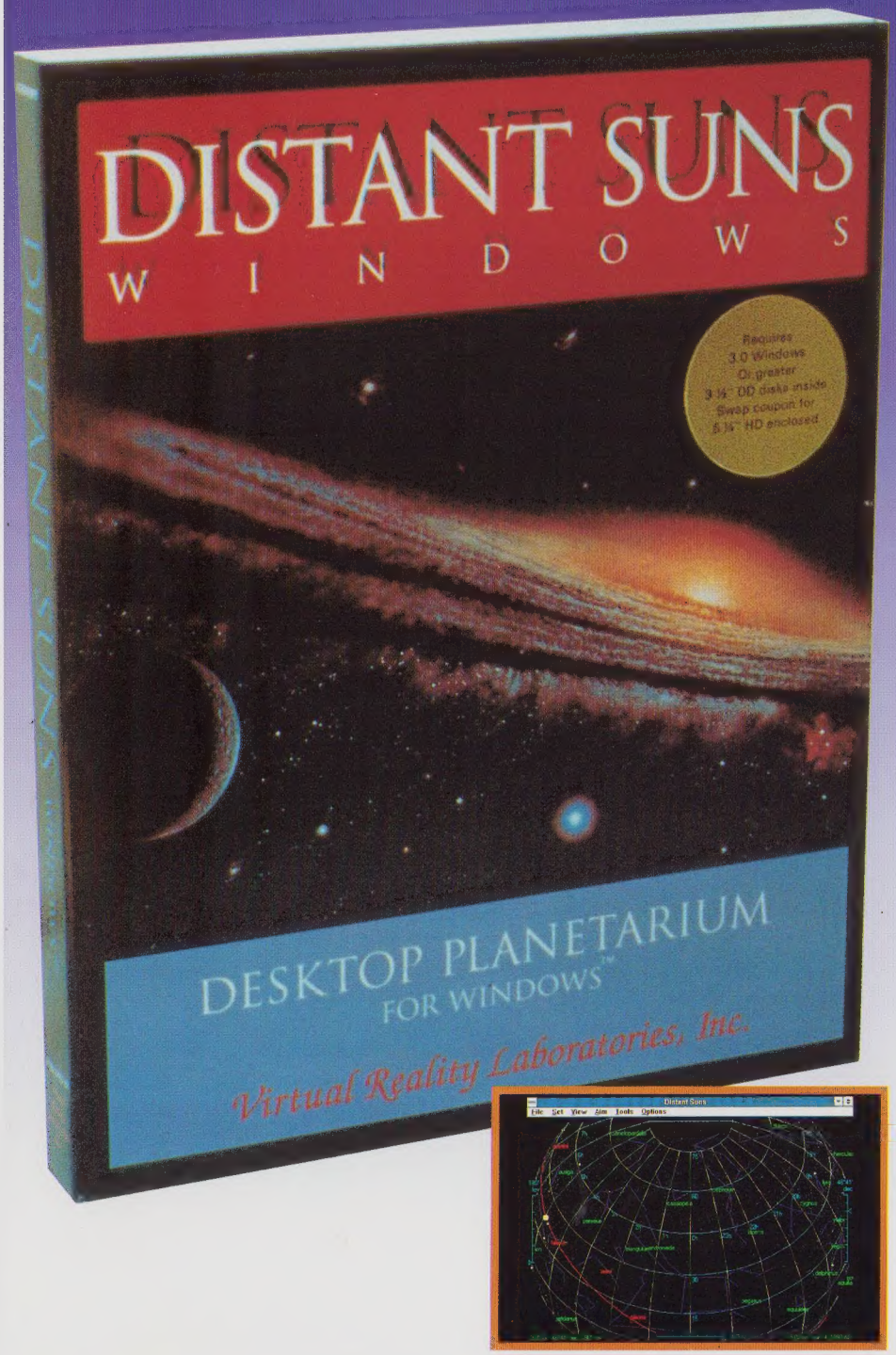

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CIRCULATION MANAGER
Michael Prior

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FOREWORD

By Jon Fairall

This is the second *Guide to Australian Astronomy*. From that, you may deduce that the first one sold in sufficient numbers for the publishers to turn a profit, albeit modest. Astronomy is probably the only scientific field in which it would be possible to make such a claim. It is interesting to ask why — after all astronomy is mostly physics with a bit of chemistry thrown in, and who reads physics books for fun?

I don't think there is any logical answer. Instead, to understand the fascination of astronomy, you have to dig deep into our roots as human beings. For the impulse that drives one to buy this magazine is the same one that drives a Jewish boy off to his bar mitzvah, induces the Muslim to face Mecca or the Christian to spend a sweltering Sunday in church. In short, a need to make some sense of it all — why are we here and what does it all mean?

That we have such a need at all must be due to the fact that we have the ability to imagine. We can imagine places we will never visit, things we have yet to build. In particular, we can imagine our own non-existence.

We need to be told what it means. In fact, it has been argued that the defining characteristic of humanness is our need to tell and be told. From the most simple to the most complex cultures people have created, this need remains constant, and is everywhere answered. It is interesting that while societies have, from time to time, denied the violence inherent in mankind, or the compassion, or the sexuality, no society has ever denied the need to be told stories.

Jon Fairall

Of course, often, perhaps mostly, those stories have been downright lies, but their function has always been the same: to make sense of the world, to unify the contradictions, to make the unpalatable, palatable.

Religions are special types of stories. Unlike, say, the dreaming myths of the Aboriginals, which are small, often contradictory stories dealing with small slices of reality, the great religions of the world attempt a comprehensive vision of space and time and our place in it. All of western literature is merely a footnote to the Bible, and I have no doubt the same is true inside Islam and Judaism.

Science, and especially astronomy, is much the same. It, too, attempts answers to fundamental questions about space and time, and our place in it. But in comparing the scientific view and the religious view of the world, it is important to distinguish between the sociology and the logic of the comparison.

Sociologically, science and religion are just expressions of the same human need. Both tell a story. Of course, the purpose of the religious view is to answer the Big Question. In science, the Big Question gets answered as a by-product of the process. But that makes little difference to the way we see it.

On the other hand, the logic is quite different, and it is in the logic that the power of science lies. Science depends on a rigorous analysis of experience, and deductions from experience based on a small set of rules of logic.

All religions are based on unquestioning acceptance of a set of propositions that fly in the face of rational belief. That is precisely their power. To believe that 2000 years ago a man was executed in hideous fashion, physically ascended into heaven and then returned to discuss philosophy with his friends is the essence of Christianity. Such a belief defines Christians, as non-belief defines non-Christians.

It's a bizarre idea. But it is not self-evidently more bizarre than the idea of curved space time or black holes.

But there are two points to note here. Firstly, science does not depend on any of its beliefs in the same way that a religion does. If the theory of black holes is all wrong then most of what scientists believe today is rubbish. But it would be of small consequence. It would still be possible to be a scientist, still possible to believe in science.

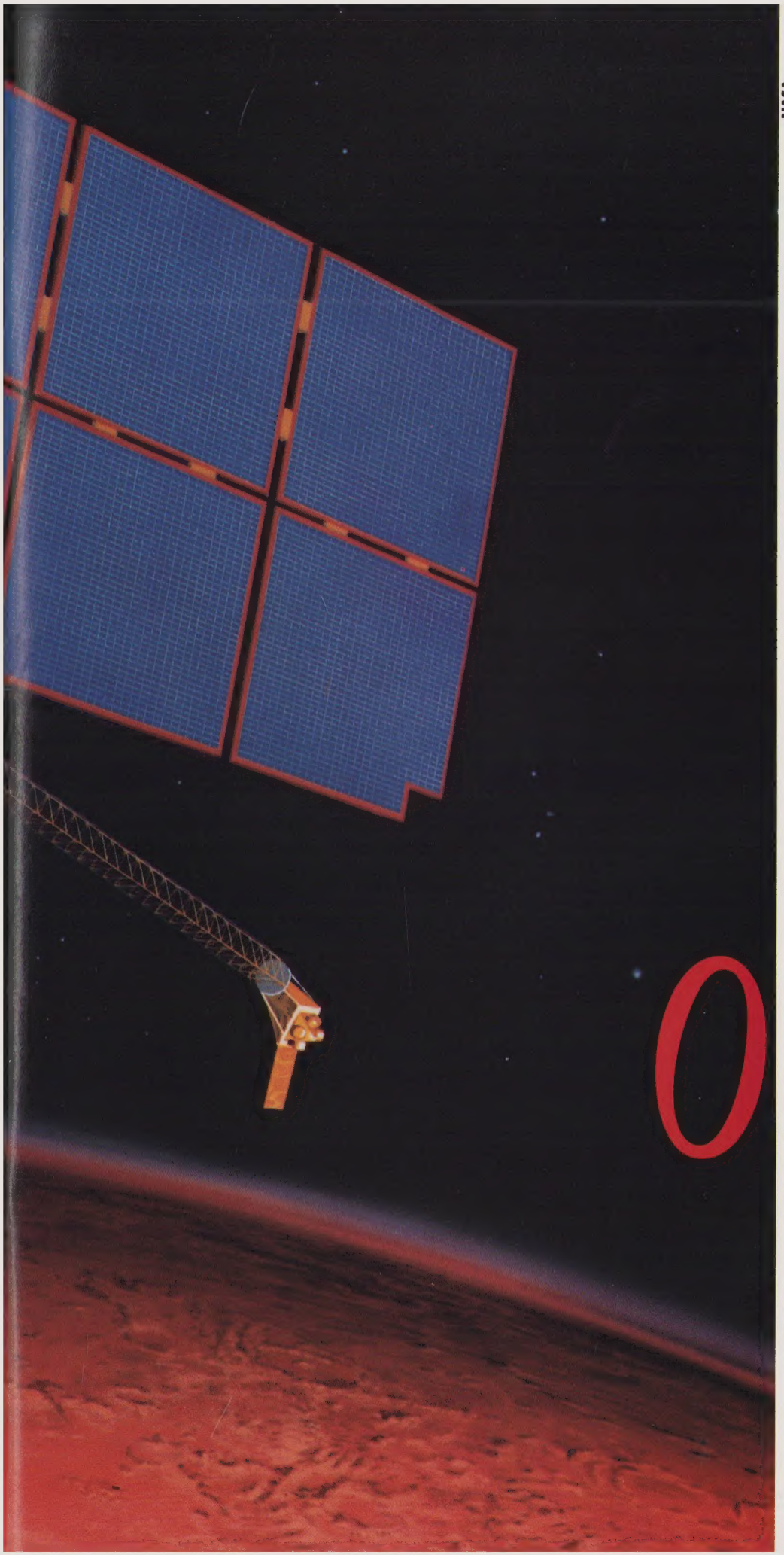
The same is not true of religion. Christianity does not exist, nor do Christians, if God did not send his only begotten son to die at Calvary.

The second point follows from the first: there is no great leap of faith involved in science. It is thus open to anybody. All that is necessary is to assent to a group of reasonably self-evident propositions, and one is in the fold. Every scientific proposition can be tested against experience. If it fails it is changed.

In the long history of science, much has changed. Much will again. As you read the stories in this book, bear in mind that much is speculation. But what a story! ...

An artist's impression of Mars Observer in orbit around Mars, sometime after October 1993. The booms carry instruments that would be affected by the power supplies or radiation from the other on-board systems.

BACK TO MARS



NASA

NASA'S MARS OBSERVER IS THE BEGINNING OF A NEW BREED OF SPACE EXPLORER. IT IS THE FIRST STEP TOWARDS MANNED MISSIONS TO THE RED PLANET.

by Kate Doolan

ONE OF THE HIGHLIGHTS OF THE International Space Year (1992), was the launch of the Mars Observer.

The US National Aeronautics and Space Administration (NASA), successfully launched its long-planned mission to Mars in October. Mars Observer is designed to take up where the Viking missions left off.

Because of its proximity to Earth, Mars has been a favourite destination for robot spacecraft from the United States, and the former Soviet Union, during all the years of the space age. The Soviets made the first attempt in 1960, but the rocket blew up on the launch pad. The first successful fly-by of the planet was made by the American Mariner 4 spacecraft in 1965.

►►►

In 1976, two Viking spacecraft, each comprising an orbiter and surface lander, arrived on Mars. For the next six years both operated flawlessly, sending data back to Earth. The data returned from the Vikings is still the best data store existent on conditions on Mars. The main finding of the flight was that Mars did not have any native life forms, either now or at any time in the recent past.

The last mission to the red planet occurred in 1988, when the Soviets launched a pair of Phobos probes. The first spacecraft failed during the journey to Mars, when ground engineers accidentally initiated a series of manoeuvres that started the craft tumbling in space. No automated recovery system had been installed in the craft, so it lost both battery power and its command link to Earth.

Phobos 2 arrived at Mars, sent home some data and some excellent images of the Martian moon Phobos, then mysteriously stopped transmitting. The problem was evidently a radio breakdown. The Soviets did not have much success in sending spacecraft to Mars.

Mars is named for the Roman God of war. It is the fourth planet from the Sun. It orbits at a distance of 227 million kilometres, and takes 687 days to go once around the Sun. The day is more or less as long as that on Earth. It has two moons, Phobos and Deimos, which were discovered by the astronomer Asalph Hall in 1877.

Ninety-five per cent of the Martian atmosphere is carbon dioxide. Surface temperatures at the Viking landing sites range from minus 14 degrees Celsius in summer to minus 120 degrees in winter.

The surface of Mars forms a bleak, rocky, red landscape with large dried up river beds. Large canyons and mountains are a prominent feature of the planet — the base of one extinct volcano, Olympus Mons, would stretch from Ballarat to Canberra and is 28,000 metres high, more than three times the height of Mount Everest.

►►►

INSTRUMENTS FOR

THERE ARE SEVEN SCIENTIFIC instruments on the Mars Observer spacecraft. The instruments will be used to provide a more detailed look at Mars than the Viking spacecraft, while giving scientists information that can be used for an eventual human journey to the red planet.

The Gamma-Ray Spectrometer (GRS), is mounted on a boom of the spacecraft. It is intended to determine the elements present on the Martian surface to a resolution of a few hundred kilometres, through measurements of gamma-rays originating at the surface. The active sensor is a high spectral resolution, germanium detector cooled to minus 560 degrees Celsius.

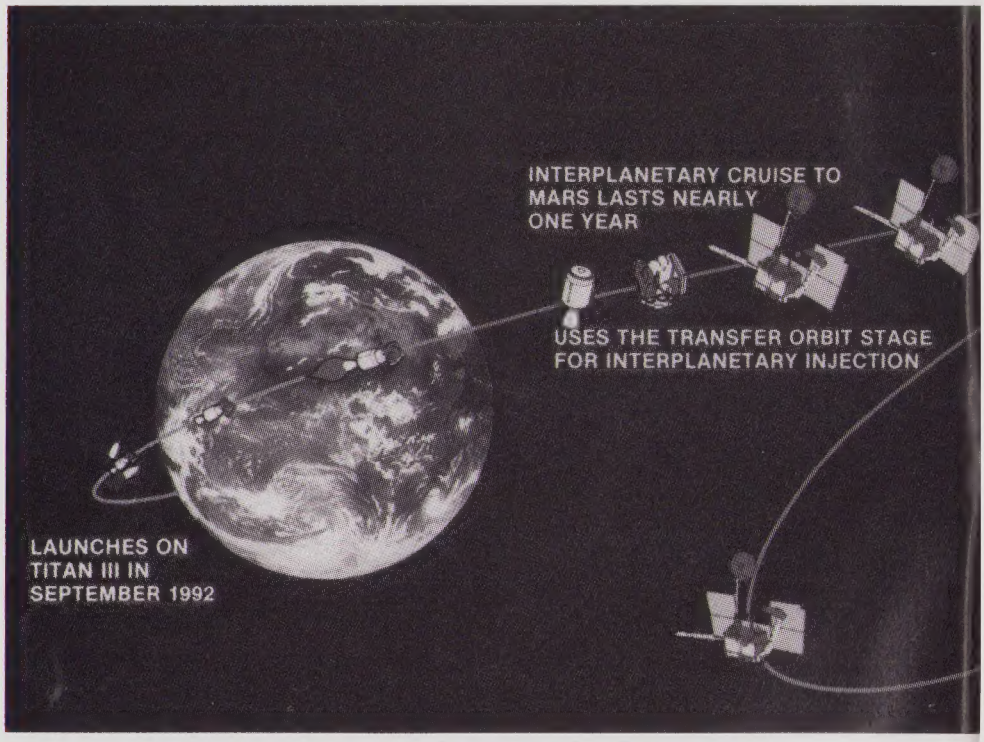
The GRS will measure the intensity of gamma rays within the range 0.2 to 10 million electron volts in Mars space. A boron-doped plastic scintillator will serve as a charged particle shield and neutron detector to determine the abundance of hydrogen.

The Thermal Emission Spectrometer (TES), is a Michaelson interferometer which uses thermal infra-red measurements to determine surface temperatures and mineral composition of the Martian surface. The objectives of this investigation are to evaluate the composition of surface minerals, its rock and ice, to map their distribution, and study the growth, retreat and energy balance of the Martian polar caps.

Other investigations for the TES include measurements of the thermal and physical properties of the surface, used to derive surface particle size, rock abundance, surface temperature, water vapour and ozone profiles.

The Mars Observer Laser Altimeter (MOLA), is designed to measure the shape of Mars precisely. The spacecraft is in orbit about the centre of gravity of the planet, so its position is known very exactly. The MOLA is a distance measuring device that determines exactly how far the Martian surface is from the spacecraft at any time.

If it works as planned, it will enable planetary scientists to establish a global topographical grid with a vertical precision of 30 metres. This will be used to get a better understanding of the planet's geology, geophysics and atmosphere.


INTERPLANETARY CRUISE TO MARS LASTS NEARLY ONE YEAR
USES THE TRANSFER ORBIT STAGE FOR INTERPLANETARY INJECTION
LAUNCHES ON TITAN III IN SEPTEMBER 1992

Trajectory from Earth to Mars. Note that the travel time is quite short, only about a year, beca
If ever Mars is colonised, the settle

PROBING MARS

MOLA consists of a diode-pumped laser transmitter and a 500mm diameter parabolic receiver. The laser illuminates a 100m diameter footprint on the surface. If laser pulses are fired 10 times a second, it allows the scientists to measure the position of the ground to within two metres.

The Radio Science (RS), experiment will use NASA's Deep Space Network (DSN), to serve as the scientific instrument for this mission. As the spacecraft approaches the limb of the Mars, it will transmit a very stable radio signal to the DSN. As the signal passes through the atmosphere of the planet, it will be altered in a number of significant ways. This makes a very sensitive probe of the constituents, pressure and temperature of the atmosphere.

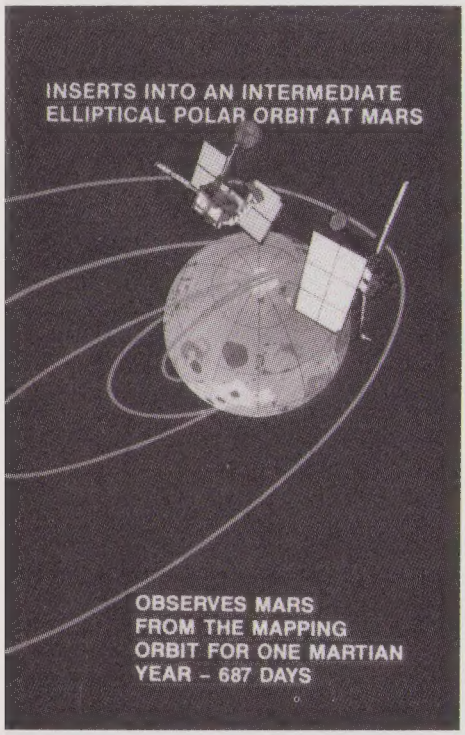
The Pressure Modulated Infra-Red Radiometer (PMIRR), has the object of mapping three dimensional and time varying thermal structures in the Martian atmosphere, from the surface to an altitude of 80km. Other goals include mapping the global vertical and temporal variations of atmospheric dust and condensates. Measurements are made in nine spectral bands with five filter channels and two pressure bands with five filter channels and two pressure modulated cells, one of which contains carbon dioxide and the other water vapour.

The Magnetometer and Electron Reflectometer (MAG/ER), uses two triaxial magnetometers and an electron reflector mounted on the six metre boom. The MAG senses the components of the magnetic field, providing its orientation and strength. MAG will thus enable planetary scientists to create a detailed map of the entire magnetic structure of the planet. The ER will be used to characterise the solar wind and the Mars plasma reactions. The ER instrument was provided by the French Space Agency.

The Mars Observer Camera (MOC), which was built by the California Institute of Technology, will produce horizon-to-horizon images with a resolution of approximately 230 metres. The telescopic images are so fine they will process less than two per cent of the planet's surface at a time. The MOC is a significant improvement over previously flown imaging systems. It has no moving parts and its exposure time is set electronically. Line arrays are read off at an appropriate interval and arranged into a picture. The MOC has a 96 Megabit memory, the most used on a planetary mission.

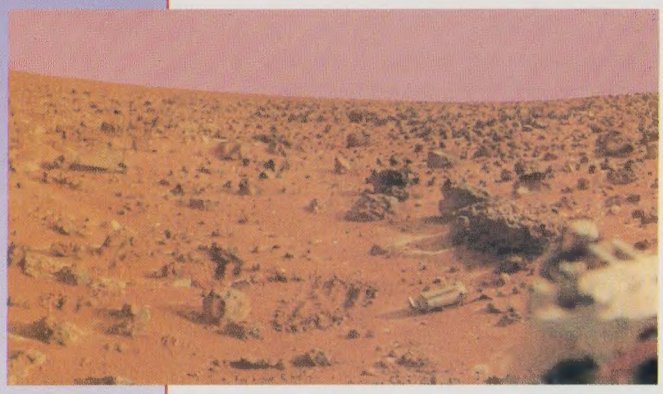
The Mars Balloon Relay (MBR), is another instrument designed by the French. It will be used to relay information from the balloons and landers the Russians are planning to put on Mars in 1996.

The MBR uses part of the video memory of the MOC as a buffer to enhance return from the instruments suspended from the Russian balloons, which are expected to include imaging, atmospheric and other instruments.


INSERTS INTO AN INTERMEDIATE ELLIPTICAL POLAR ORBIT AT MARS
OBSERVES MARS FROM THE MAPPING ORBIT FOR ONE MARTIAN YEAR – 687 DAYS

e the two planets are in the optimum position. nay have to endure considerably longer trips.

Like Earth, Mars has ice caps at the North and South poles. They contract and expand during the Martian winter and summer.



JPL

Think of a gibber plane out west of Lake Eyre, make it freezing cold instead of boiling hot, make the sky pink instead of blue, and remove all forms of life. Welcome to Mars. This picture was taken by Viking 2 on Mars in 1976.

As a place for a holiday, it would be somewhat less hospitable than the South Pole. Nevertheless, it appears to be the only place in the solar system where life might be possible. It's a possibility that has tantalised generations of thinkers. So it should come as no surprise that, notwithstanding the lack of concrete missions, the planet has been central to much discussion about the direction of US space policy.

Should a manned flight to the red planet be part of NASA's overall mission statement? If Mars Observer is successful, manned flights could occur with 25 years.

The Mars Observer spacecraft was originally conceived during the early 1980s, when NASA established a Solar System Exploration Committee at its headquarters in Washington, DC, to determine what direction solar system exploration should take during the '80s and '90s.

One of the suggestions was for a Mars orbiter to be launched in the late '80s. Initially, it was known as the Mars Geoscience/Climatology Orbiter, which makes neither a useful acronym or an easily remembered name. It was therefore renamed the Mars Observer, and responsibility for the mission was passed to the Jet Propulsion Laboratory (JPL), in Pasadena, after approval to build the

►►►

spacecraft was granted in 1985.

Originally scheduled for launch aboard the space shuttle in 1990, the date was changed to 1992 after the Challenger disaster in 1986. It was also decided to launch the Mars Observer aboard a Titan III expendable launch vehicle.

The Mars Observer design is based on those of RCA communications and defence spy satellites, but has been modified for this flight. Weighing 2487 kilograms, it consists of two main parts: the spacecraft itself, known as the bus, and the science instruments, known as the payload.

Mars Orbiter is currently in cruise mode, on route to Mars. This section of the trip will last for 11 months. It began when the Mars Observer separated from its Transfer Orbital Stage, a small rocket motor designed to shift the Orbiter out of Earth orbit into the Mars transfer ellipse. This is an orbit around the Sun, with one end at the Earth and the other at Mars. For eleven months, Mars Observer will be yet another minor planet of the Sun. This stage will end, in October 1993 when Mars orbital insertion begins.

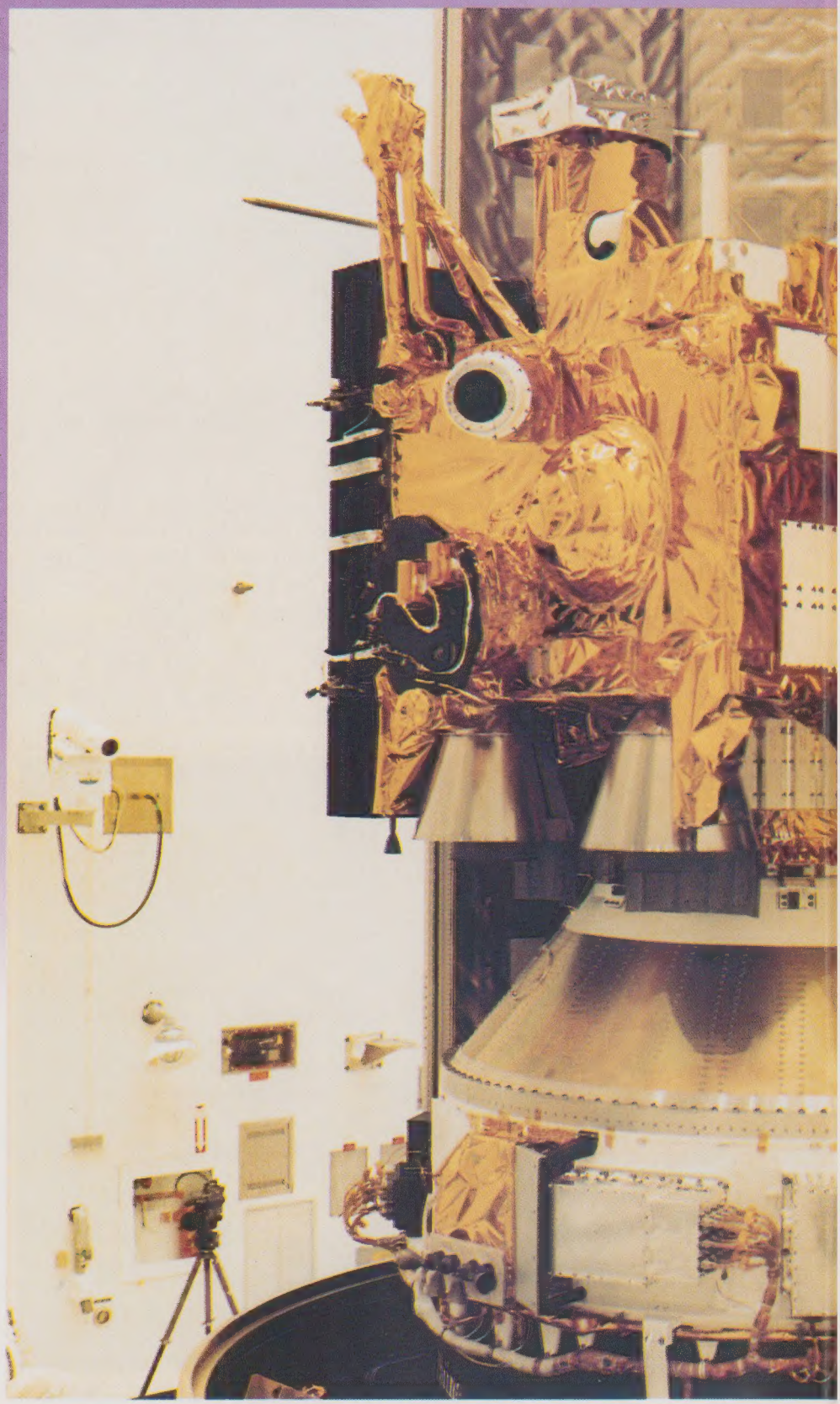
The mapping phase, which begins when Mars Observer reaches its orbit in Mars, is scheduled to last for a full Martian year, or 687 days.

There has been a great deal of cooperation between the former Soviet Union and NASA on the Mars Observer project. Besides the relay system being used for the Mars 1996 mission (see *Instruments for Probing Mars*), 10 CIS scientists will be part of the science investigation team.

The Mars Observer should answer many questions about the planet Mars, and will be a perfect reconnaissance craft for the scientists and engineers who will one day design manned spacecraft to follow in their foot steps. ◐

NASA's DEEP SPACE NETWORK (DSN), will be used for communications between the spacecraft and ground controllers. The 34-metre, high

TALKING



Mars Observer unclothed. This picture shows the spacecraft and the transfer stage booster just prior to being placed in the nose of the Titan rocket that sent it aloft. The golden foil over the outside is a thermal blanket that regulates the temperature of the spacecraft. ▶

TO MARS

NASA

efficiency subnet — one of the newest DSN subnets — has been selected to provide the daily uplink and downlink communications with the spacecraft at frequencies of 7.2 and 8.4GHz respectively. The subnet will provide telemetry for the spacecraft (at data rates from 7.8 to 500 bits per second), radiometric data, two way doppler ranging and very long baseline interferometry, radio science and DSN monitor data. The DSN-70 metre telescope will provide periodic real time high rate telemetry and radio science support.

The Mars Observer used two types of data return: recorded and real time. For recorded data, the playback rates are 21.3, 42.7 and 85.3 kilosymbols per second, (corresponding to record rates of four, eight and 16 kilobits per second). The 48.9 ratio between playback and record was selected because in a typical eight hour DSN tracking pass, a minimum playback of 4.5 hours is available out of every 24, due to Earth occultations.

The playback rates were selected to cover the range of expected telecommunications capabilities as the Earth to Mars distance will vary greatly during the mapping phase. There will be a delay of up to 40 minutes each way for communications between Earth and the spacecraft, (compared to 4.5 hours each way for Voyager at the Neptune encounter). The spacecraft has three tape recorders which can store up to 48 hours of data at the four kilobit per second rate.

The spacecraft has a high gain parabolic antenna measuring one and a half metres in diameter and three low gain antennae.

MARTIAN POWER

MARS OBSERVER IS powered by an electrical power subsystem to provide the generation, storage, control and distribution of electrical power during flight.

During the launch, ascent, and parking orbit stage of the flight, power was provided by nickel cadmium storage batteries.

When the spacecraft was launched, the antenna, instrument booms and solar arrays were folded close to the bus — which has a box shape and is three metres high, three metres wide and three deep.

However, after separation from the upper stage, power was generated by the solar panels.

The solar panels are two and a half metres in diameter. Four are currently deployed. The remaining two will be unfolded when the craft reaches Mars orbit. The six panels of the solar array are arranged in a two by three matrix.

They are designed to provide sufficient power for the normal operation of the craft, as well as recharging the batteries. They are capable of delivering a maximum load current of 30 amps to the normal electrical bus and a further 25 amps to the battery charge circuit — a total of 55 amps.

Far beyond the orbit of Pluto, in the cold darkness of deep space, lies the realm of the comets. Although it has never been seen, scientists believe that a huge sphere of billions of comets completely surrounds our solar system. Occasionally, some of them are nudged into different orbits, and then spiral into the inner solar system where the sunlight causes them to grow their familiar tails. Main picture by Eleanor Helin and copyright JPL; inset taken by the Giotto space probe, copyright European Space Agency.

IS TH

THE SEARCH FOR A TENTH PLANET CONTINUES, DESPITE MOUNTING EVIDENCE THAT WE HAVE DISCOVERED ALL THE MAJOR PLANETS IN THE SOLAR SYSTEM.

E ARE TAUGHT IN SCHOOL THAT THERE ARE NINE planets, including the Earth, circling around the Sun. We are made to learn their names and the order of their orbits, from innermost Mercury to outermost Pluto. Yet as recently as 63 years ago, school children were taught that there were only eight planets (including Earth), orbiting our sun. The tale of the discovery of Pluto, and before that, Uranus and Neptune, is a fascinating one. But some people believe that the tale is not yet complete. These are the believers in Planet X.

Five of the major planets have been known since ancient times — Mercury, Venus, Mars, Jupiter and Saturn. This is not surprising, for on the whole they are much brighter than the stars, and they are noticeably different in that they move with respect to the other stars. The ability of these 'stars' to move in the sky quite impressed the ancients, and they assigned special significance to them, even to the extent of naming them after [illegible]. The word 'planets' is taken from the Greek word of that meaning.

[illegible] English amateur astronomer William Herschel, accidentally discovered Uranus during a search for comets. Indeed, at first he mistook the faint disc of light for a comet. It wasn't until some months later, when an orbit had been calculated, that it was realised that what he had found was not a comet, but a new planet. The planet was named Uranus, after the Greek god of the heavens. (Incidentally, it was determined later that the slow moving planet had been spotted many times before, but had always been mistaken for just another star.)

Unlike Uranus, however, the discovery of the next furthest planet, Neptune, was not accidental. Calculations of Uranus' orbit disagreed with its observed position, and it was thought that there must be another planet further out that was [illegible] out to predict the location of the new planet.

The first was John Adams, an Englishman in his early twenties, who in 1845 sent his mathematical prediction of the

Eleanor Helin. Inset: European Space Agency

ERE A PLANET X?

by Jonathan Nally

position of the undiscovered planet to the English Astronomer Royal, George Airy, and James Challis, another eminent astronomer. Neither man chose to take the matter any further.

At almost the same time, a Frenchman, Urbain Jean Joseph Leverrier, arrived at virtually the same conclusion as Adams. Comparison of the two predicted positions showed that they were almost identical. Leverrier, too, did not have any luck persuading his French astronomical colleagues to look for the planet.

It took a plea the following year from Leverrier to German astronomer Johann Galle at Berlin Observatory for his pre-diction to be tested. The new planet was found within hours by Galle and a student, Heinrich D'Arrest, very close to where Leverrier had predicted it to be. The new planet was named after the Roman god of the sea, Neptune.

But a mystery remained. Both Uranus and Neptune's orbits still appeared to be affected by an unknown gravitational pull. It seemed that there must be another planet, further out than Neptune, that was affecting the orbits of the two giant planets. The problem was, how to find it?

Astronomers used the irregularities of Uranus orbit to calculate the probable position of the extra planet. Neptune's irregularities were too uncertain due to a lack of observations. (To accurately predict an orbit, many observations spread as far as possible along an orbit are required; Neptune revolves so slowly around the Sun that there was insufficient coverage of its orbit.)

Several predictions were made, but none of them bore fruit. It wasn't until a young American astronomer, Clyde Tombaugh, undertook an exhaustive photographic survey at Lowell Observatory in Arizona, that the new planet was found in 1930. It was named for the god of the underworld, Pluto.

With this discovery, it was thought that the search had been successfully concluded. The irregularities in Uranus and Neptune's orbits could be explained by Pluto's distant gravitational pull, and the outer limit of the solar system had been finally determined.

Unfortunately, it was later found that Pluto simply could not have been the culprit behind the other two planet's irregular motions. With the discovery in 1978 of Pluto's moon, Charon, came the realisation that Pluto was a lot smaller and a lot less massive than had been supposed. It could not possibly have had the required gravitational influence on Uranus and Neptune. In other words, the discovery of Pluto was serendipitous — it was not the predicted planet after all.

So is there another major planet to be found beyond Pluto, a Planet X? The modern astronomical community is divided on this question. Many astronomers are of the opinion that we have discovered all the major planets that are to be found. Others haven't given up hope, and are continuing the search.

Those who are not believers in Planet X think they have good reason to doubt.

When Tombaugh discovered Pluto in 1930, even then it seemed suspiciously small. Tombaugh continued his photographic search for another thirteen years. When you include the first search, all up he covered about 75 percent of the sky, around 90,000 square degrees. Apart from Pluto, he spotted 3,969 images of asteroids, 1,807 variable stars and one comet. He even discovered a new globular star cluster. But he did not find any other new planets.

That Tombaugh's extremely thorough search failed to reveal another planet is just one of the reasons that many astronomers doubt the existence of a Planet X. Another is the failure of the Infra-red Astronomical Satellite (IRAS), to spot any solar system object beyond the orbit of Pluto.

Launched in 1983, the short lived IRAS satellite was equipped with sensitive infra-red ('heat') detectors which

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surveyed almost the entire sky at several infra-red wavelengths. IRAS found a multitude of infra-red radiation sources within our galaxy, and even discovered many comets within our own solar system. But it did not find anything remotely resembling a trans-Plutonian planet.

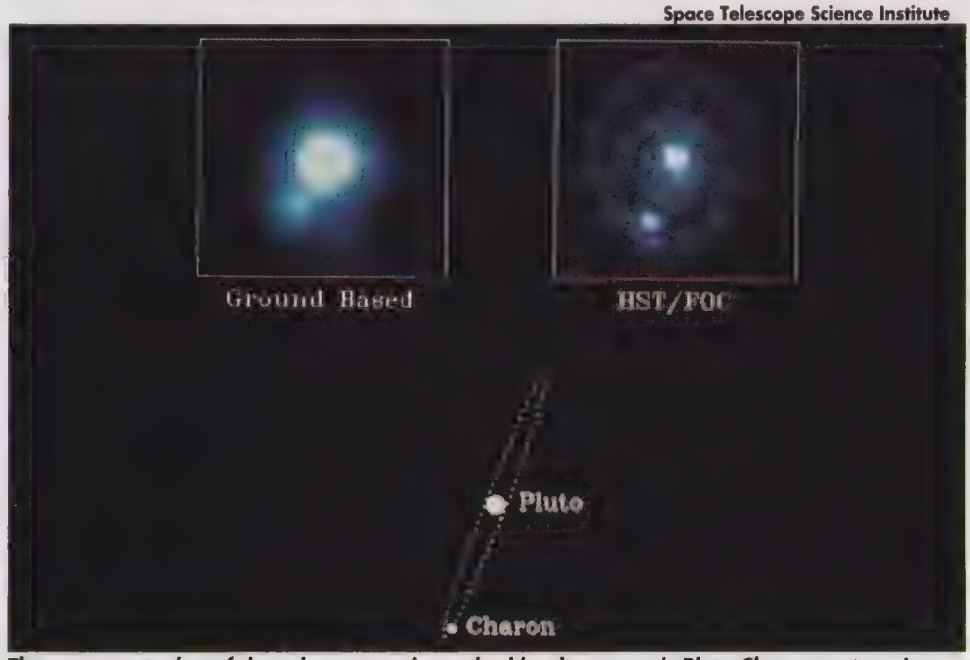
It is possible (though unlikely), that IRAS may have missed Planet X. Perhaps Planet X was in the four per cent of the sky not covered by the IRAS survey. Perhaps it was too dim for IRAS to pick out, or maybe it was hidden amongst the background clutter of the Milky Way. Finally, there is the possibility that Planet X is moving so slowly that the scientists, on the lookout for a faster moving object, might have overlooked it, thinking that it was just another star. All the infra-red survey data is recorded and still available for study, and indeed many intriguing infra-red discoveries have been made simply by going back through the data and having a closer look. But most astronomers believe that if anything substantial is out there, it would have been found in the IRAS data.

The third strain of evidence against Planet X involves the same observed orbital irregularities of Uranus and Neptune that led to the coincidental discovery of Pluto. It turns out that predicted positions for Uranus and Neptune are accurate only for a period of about ten years, and then they start to differ significantly from the observed positions. The difference is very slight, no more than one second of arc, (which is 1/3600th of a degree). A team of Canadian researchers have recently argued strongly that the irregularities do not really exist. Rather, they claim the difficulty astronomers have reconciling the observed and predicted positions of the two planets, stems from nothing more than systematic errors and minute inaccuracies in past observations of the two gas giants, which have led to imperfect predictions.

As mentioned above, the longer you can observe a planet during its orbit, or the more complete orbits you can observe, the better you are able to predict a planet's position in the future. For the inner planets this is a relatively easy affair; their orbital revolutions are short enough — from Mercury's 88 days to Saturn's 29.5 years — for accurate measurements to be have been made over many orbits. Uranus, however, orbits the Sun every 84 years, whilst Neptune takes an enormous 165 years. In other words, our modern, ultra-precise measuring techniques have been applied to these planets, and in particular Neptune, for only a limited time, and there is a growing suspicion that it is simply the inaccuracies of earlier observations that are throwing out the orbital predictions.

The final difficulty with the notion of a tenth planet, has to do with the theories of origin of the solar system and of the planets in particular. The generally accepted theory of planetary origin has the solar system forming out of an enormous cloud of interstellar gas. The gas cloud contracts under its own gravity, and begins to spin. Clumps form within the spinning disc of gas, and over a very long period of time merge to form planets.

Space Telescope Science Institute



The outermost edge of the solar system is marked by the eccentric Pluto-Charon system. Is there a Planet X beyond the orbit of Pluto? Some scientists believe that there is, although others are beginning to doubt. Pluto is so far away that the image on the right, made with the Faint Object Camera aboard the Hubble Space Telescope, is the best that scientists have ever managed to take of the distant planet. The image on the left is from ground observation.

In the inner solar system, rocky planets with thin atmospheres formed — Mercury, Venus, Earth and Mars. Farther out, where the temperatures were cooler, gas giant planets formed — Jupiter, Saturn, Uranus and Neptune. Pluto seems to be the odd planet out. It is small and icy, similar to several moons of the gas giant planets, but is in a very strange orbit — highly elliptical and highly inclined to the plane of the other planets. Many astronomers think that it could have been a moon of Neptune which was flung off in a gravitational encounter, al-though the discovery of Pluto's own moon, Charon, has cast some doubt on this.

If Pluto did not form in its present orbit along with the other planets, though, then it could be that the natural outer limit of the realm of the major planets is Neptune.

Arguments in favour of a tenth planet have for a long time relied on the orbital irregularities of Uranus and Neptune. Yet even though evidence is accumulating to suggest that this may not be the case, there is still a possibility of finding a body orbiting further out in space. Indeed, for a long time astronomers have been aware of many bodies that dwell far beyond the boundary of Pluto's orbit. These are the comets.

Comets are balls of ice and dust, with nuclei ranging in size from hundreds of metres up to a hundred kilometres. When they sweep into the inner solar system, the Sun's radiation evaporates ices on their surface, causing them to produce an enormous spherical cloud of gas and dust which surrounds them and completely hides the nucleus. A lot of this gas and dust is swept into a majestic tail by the pressure of solar radiation.

Neptune was the first planet to be discovered as part of a deliberate search. Astronomers had noticed inaccuracies in their predictions of Uranus' orbit, and they realised that this was caused by the gravitational pull of another, unseen planet. Mathematicians used this information to predict the position of the extra planet, and on September 23, 1846, Neptune was found. However, there remained unexplained inaccuracies in the orbits of both Uranus and Neptune, leading to speculation of the existence of another planet. When Pluto was discovered in 1930, astronomers thought they had the answer, but they now know that Pluto is too small to have the required gravitational influence. Some astronomers are now saying that there is nothing wrong with the orbits of Uranus and Neptune, that it is only the inaccuracy of our measurements that is causing the problem.

NASA

By following the orbits of comets back, it can be seen that many of them have come from deep space, far beyond the orbit of Pluto. It is thought that there must be a giant reservoir of comets lurking at an enormous distance from the Sun. Since comets can come in from any direction, not just within the plane of the planets, this reservoir must be spherical and surround the whole solar system. This is known as the Oort Cloud, after the Dutch astronomer who first put forward the idea.

The Oort Cloud must be a long way out, probably 50,000 times farther out than Pluto, and contain billions upon billions of comets. Over millions of years, the tiny gravitational influences of nearby stars, giant galactic gas clouds, and the gravitational tide of the galaxy as a whole, causes some of these distant comets to shift orbit, eventually spiralling in towards the Sun. These are usually the biggest and brightest comets. Many of them pass through the solar system once and never return.

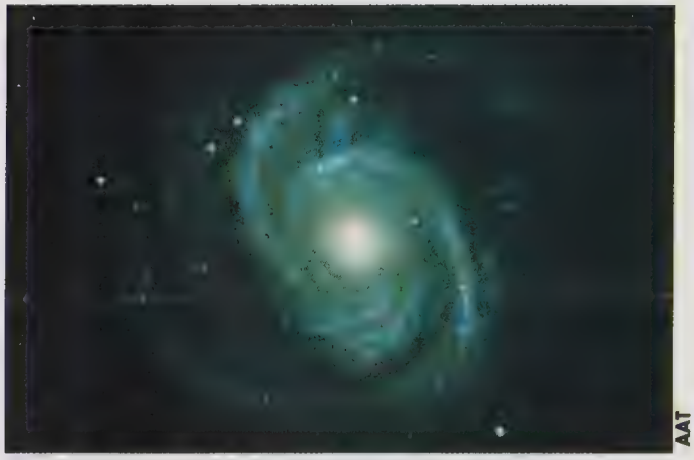
More recently, an additional reservoir of comets has been proposed. This is the Kuiper Belt, a disc-like grouping of comets thought to occupy a region around 5,000 Pluto-radii out from the Sun. The Kuiper Belt is believed to be the origin of the short-period comets — those with orbital periods of 200 years or less — which fall into the solar system and become gravitationally trapped in short-period orbits.

Some astronomers have suggested that the gravitational influence of the Oort Cloud and Kuiper Belt may be the reason behind Uranus and Neptune's apparent orbital misbehaviour, but the idea is not widely accepted.

So where does this leave the hunt for Planet X? The consensus at the moment seems to be that a tenth major planet probably does not exist. The failure of IRAS to find it, and the recent alternative explanation of Uranus and Neptune's orbital peculiarities are strong arguments against Planet X. If Planet X does exist, it is puzzling that it has not yet been found.

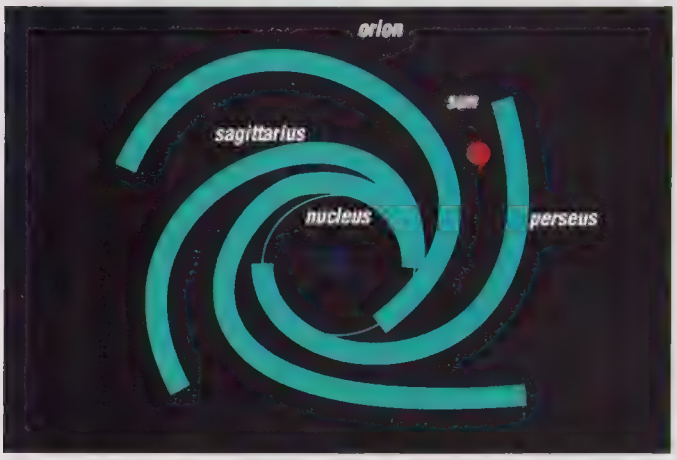
Yet some astronomers are continuing the search. Maybe when the new European Infra-red Space Observatory is launched later this decade, they'll have an increased chance of making a new planetary discovery. Indeed in recent months, American astronomers have discovered a large body orbiting our Sun just beyond Pluto. Designated 1992 QB1, it seems to be a large (200km diameter), asteroidal or cometary body, but it is too small to be Planet X. Time will tell whether a Planet X exists, but the astronomical consensus seems to be not to hold your breath. ◐

Jonathan Nally is editor of Sky & Space, *the Australian bi-monthly astronomy and space magazine.*



AAT

Messier 100, a spiral in Virgo. Seen from outside, our own galaxy, the Milky Way, would look something like this.



The sun is located about two thirds of the way out from the core of a spiral galaxy. Between us and the centre of the galaxy lie the Orion and Norma arms. The Pereas Arm lies between us and open space.

HOW FAR

THE DISTANCE TO THE STARS HAS BEEN A CENTRAL PRE-OCCUPATION OF ASTRONOMERS SINCE TIME IMMEMORIAL. MODERN ASTRONOMERS USE A WEALTH OF PRECISION DATA TO HELP SOLVE THE SAME QUESTION.

ASTRONOMERS LIKE TO TELL YOU that space is big. The first chapter of *The Hitchhiker's Guide to the Galaxy* reminds us that the universe is 'really big'. Other sources use words like 'vast'. But if you go out on a clear night, far from the city lights, and look into space, you will see nothing but stars of greater or lesser brightness. Some look so close you could touch them. There are no tape measures, no mile pegs. Is Sirius really further away than London?

How do scientists know the distance to the stars? In detail, the story is a wonderful mixture of theory and observation, and most good astronomy texts elaborate in much detail. But in this article, I want to skate over the subject, showing you the main chapters. It's a subject that breaks naturally into different divisions, because so many different methods are used. When you consider the range of distances involves, from 500km above our heads, where the atmosphere ends, to the edge of the visible universe, billions of kilometres away, this is hardly surprising.

The key to distance in space, and thus to virtually everything we know about the stars, is parallax. It's really simple. Hold up a finger at arms length. Close one eye, then the other; see the finger appear to move?

Now remember some basic trigonometry, and convince yourself that there is a very definite relationship between the distance between your eyes, the distance to your finger, and the amount it appears to move. It's by exploiting this relationship, and making measurements of fantastic precision, that astronomers have unlocked the distance scales of the universe.

Of course, it doesn't help an astronomer much to close one eye or the other, but the same effect can be created by moving the telescope from one point to another. (See *The Parallax Question.*) This method formed the first real evidence for the size of the solar system and thus allowed astronomers to accurately measure the size of the Earth's orbit. In 1671 Frenchman Jan Richer led an expedition to French Guiana and observed Mars at the same time as Giovanni Cassini in Paris. They came up with a value of 139 million km. Today, after two centuries of parallax observations of the planets, as well as bouncing radar off the Moon and Venus, we accept 150 million km as the true value. For convenience, we'll call this an astronomical unit, (au).

This method, however, is really restricted to the solar system — the planets around the Sun. The stars are so far away that shifting a telescope shows little measurable parallax. However, there is a way to create a much longer baseline, and

ARE THE STARS?

by Jon Fairall

AAT

30 Doradus in the Large Magellanic Cloud. This is the brightest and most luminous stellar object of which we have knowledge. When all else fails, astronomers can estimate the distance to faint galaxies by assuming that the brightest star visible is as bright as 30D. This method is actually more powerful than it sounds. 30D is probably as big as it is possible for a star to get. It is quite reasonable to suppose that out of the billions of stars in an individual galaxy, at least one will approach this limit.

that is to allow the Earth to move around the sun. By waiting six months, an astronomer can build a baseline of two astronomical units.

About 6000 stars are now known to have 'annual parallax'. They describe a small ellipse against the background stars because the earth moves relative to the Sun. But note that the operative word here is 'small'. The closest star is Proxima Centauri, which has a parallax of 0.76 arc seconds. (There are 3600 arc seconds in a degree.) This means it is 271,538 au from earth.

Notice that in describing the closest star, the numbers are already getting very cumbersome. Astronomers use parsecs as a measure of distance. At one parsec — 206,000 au or 30,900 billion km — a star has a parallax of one arc second. As these things are counted, a parsec is still right on our doorstep. Proxima is thus 1.3 parsecs from Earth.

The problem with parallax as a measure of distance is that — even using the Earth's orbit for a baseline — it runs out of steam so quickly. At 10 parsecs, a star has a parallax of 0.1 arc seconds. At 100 parsecs, 0.01 arc seconds. This is a fantastically tiny angle, and in fact, it is smaller than the best telescopes can measure. Even the Hubble Space Telescope can only achieve 0.1 to 0.15 arc seconds. In practice, astronomers can make position measurements with about plus or minus 0.005 arc seconds, which means figures for parallax much smaller than 0.01 arc seconds parallax should be taken with a grain of salt.

So, this limits direct measurements of stellar distances to less than 100 parsecs. But space is much bigger. Where do we go from here? Fortunately, there are two indirect routes that yield information about stellar distances much further out.

Within 100 parsecs or so there are sufficient stars for us to be able to develop some coherent models of how stars shine, how hot, how big, and so on. Since we know how far away they are, we can isolate the effect of distance, and determine, for instance, the luminosity of the star. Luminosity is the total energy coming out of the star. Analysis of the close stars has shown that the luminosity of a star is a function of its surface temperature. Surface temperature can be determined by studying its spectrum.

For the majority of stars — so-called main sequence stars — it turns out that this is a quite straightforward relationship. It is complicated by the fact that some stars are very much brighter

This diagram shows the luminosity of stars in the local area mapped against their colour. The diagonal band is called the main sequence. The stars at bottom left are called white dwarfs, and those at top right red giants. Diagrams like this are fundamental to astronomy. They are known as Hertzprung Russell diagrams in honour of the two astronomers who first analysed stellar populations in this fashion.

or dimmer than they should be, indicating that they are very much larger or smaller than expected. These are the dwarf and giant stars. Nevertheless, by examining the spectra of these stars closely, it is possible to tell the difference, and to make a reasonable estimation of their luminosity.

This gives astronomers a very powerful method of determining distance. If we can obtain a spectrum from a star, we can tell how hot it is, hence its luminosity. Armed with its luminosity, it is straightforward to determine its distance. We can compare how bright it seems to us, with how bright it actually is.

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There is just one complication, which for many years confused much astronomy, and that is called interstellar reddening. Star light appears to loose energy — become red — as it travels across space, because of encounters with clouds of dust and gas. Thus distant stars appear further away that they actually are.

So, effectively we can measure the distance to a star as long as we can see its spectrum and measure its magnitude. By studying some of the hottest and most luminous types of stars, astronomers have been able to map the sky in three dimensions.

As a result, we know that the Sun is buried in a vast spinning mass of stars. We know this mass of stars has a flat pancake-like shape, and that we live in one of its spiral arms. They are visible to the naked eye as the Milky Way. Statistical studies of very hot stars within the Milky Way have shown they appear to lie in three clumps, corresponding to three distinct arms.

It's very difficult to study the galaxy from the inside, because dust obscures the view, but we know something about the scale of our galaxy. Studies of globular clusters — large assemblies of stars — have found they are centred on a spot about 10kpc (kiloparsec = 1000 parsecs), from us, and studies of very bright variable stars called RR Lyre stars show a distribution about 8.7kpc. Somewhere between these numbers is the centre of our home galaxy.

Is the home galaxy all there is? From the 17th Century, astronomers had been aware that not all objects in the sky were stars. Some were fuzzy clouds, called nebula. These were objects of controversy. Some, like the philosopher Kant, argued they were all island universes, comparable to our own. Others argued that they were simply features of our own galaxy.

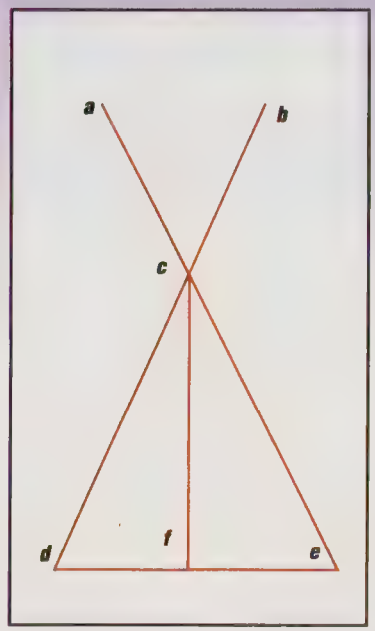
In the end, it was statistics that solved the problem. A careful watch was kept on the Andromeda nebula — the biggest nebula in the sky — to detect nova. Many were, if fact, observed, which lead to the conclusion that it was indeed

THE PARALLAX QUESTION

PERHAPS THE MOST famous example of moving a telescope around the Earth to find astronomical distances was that of James Cook, on his way to discover the east coast of Australia. To understand, consider the state of 18th Century astronomy.

During the preceding 200 years, Kepler, Newton, Copernicus and others had defined the general shape of the solar system, and shown that it was possible to relate orbital periods to distance.

Johannes Kepler had shown that if you square the time taken for a planet to go around the Sun, you have the cube of the Sun-Planet distance. So if one could express the orbit of any object in the solar system in years, its distance in astronomical units, ie in terms of the Earth-Sun distance, followed naturally.



Parallax. You can do it yourself by closing one eye at a time. Astronomers do it by making observations from different points.

Thus astronomers knew that Jupiter takes about 12 years to go around the Sun, so it is just over five times further from the Sun than the Earth. What they did not know was the distance in kilometres. They had a map of the solar system, but it was a map without a scale.

Hence the importance of parallax. If one distance — that between the Earth and a planet, or a planet and the Sun were established — all other distances would follow.

Edmund Halley, who became famous by predicting the return of the comet that now bears his name, pointed out that one time when it would be possible to do this was during a transit of Venus — when Venus passes in front of the sun. So Cook was dispatched to the South Seas, aiming to time the transit of Venus in the Pacific, while his colleagues did the same thing in London.

In the event, Cook only half succeeded. The observations were partially at fault, since the sky was hazy, and his instruments were out of adjustment. Values between 155 and 149 million km were obtained, only a little better than the results of 1761, when European observatories had achieved values between 175 and 125 million km. Belatedly, observers realised that atmospheric effects on Venus play havoc with the readings.

Nevertheless, Cook's results served to confirm that astronomers understood, at least approximately, the scale of the solar system.

By using the orbit of the Earth, it is possible to create a very long baseline.

AAT

The globular cluster 47Tuc seen through the 4 metre at Siding Spring. A cluster like this contains millions of stars. Astronomers like to study them, because some clusters are close enough to show individual stars. Since all the stars are more or less at the same distance from the Earth, we can compare them in the knowledge that any differences we see are real, and not caused by distance.

composed of stars, and had to be a separate star system.

In 1923 the American astronomer Hubble detected stars called Cepheids in the outer reaches of Andromeda. This clinched the matter, and set Andromeda's distance at 245kpc. Andromeda really was a separate island universe, just like our own.

As it has turned out, it is these Cepheids, rather than novae, that have been the key to the jump from our galaxy to external galaxies. Cepheids are variable stars. Named for the star Delta Cephei, Cepheids were at first dismissed as just another class of hot variable stars. Variable stars get brighter and dimmer over a regular time period.

They were first studied systematically by Henrietta Leavitt in 1912, who examined those in the Small Magellanic Cloud, a small, close galaxy. In fact, it is one of the closest galaxies, but fortunately far enough away so that variations in the distance to individual stars is small.Leavitt noticed that there was a relationship between the luminosity of her Cepheids and their period. The brighter the star, the longer the period. This effect had not been noticed before in Cepheids in our own galaxy, the effect being masked by distance. Leavitt realised that Cepheids could be important distance markers in the Universe, but they needed calibration. The nearest was beyond the range of parallax. A single distance to a Cepheid would suffice.

Once the importance of Cepheids was understood however, they were discovered in globular clusters and in other sites where there were independent methods of determining distance.

Cepheids form an important new tool for astronomers interested in distance scales. They are supergiants — the hottest, and therefore most luminous type, visible over the greatest distances. Secondly, an astronomer can watch the period of a Cepheid when it is quite impractical to obtain a spectrum from it. As a result, Cepheids are used to probe the closest galaxies.

The first time this was done was by Hubble in 1923, while studying Andromeda. However, it later turned out there was a subtle distinction between Cepheids, one group being more luminous than the second. These are known as RR Lyre stars after the first one discovered.

Once the question was settled, the distance scale of the universe grew dramatically. Since the middle of the 19th century, many galaxies like Andromeda had been

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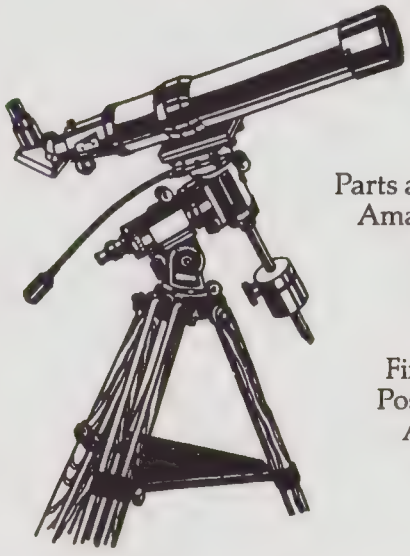

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identified, so that in 1923, at least 2000 extra-galactic objects could be identified. As with using parallax in the stars, a study of the close ones, where distance could be determined, revealed information that could be used to calibrate a distance scale.

In the case of galaxies, the distance scale was furnished by a remarkable fact. A close inspection of their spectrum showed they were all receding from us.

constant. Newer and better telescopes have allowed the detection of Cepheids in more and more distant galaxies. One of the driving forces behind the creation of the US Space Telescope (also known as the Hubble Space Telescope, for obvious reasons), was a desire to probe distant galaxies for Cepheids, in order to refine the value of H, and thus to define the size of the universe. As it turns out, this is quite impractical given the current state of the instrument. Astronomers learn to live with such disappointments.

Mount Palomar

M31, The Andromeda Galaxy. This is another sizeable member of the Milky Way. 670 kpc away, it is the most distant object visible with the naked eye. It is especially important to the development of astronomy, because Nova and Cepheid variables in its arms confirmed it was an object external to our own galaxy. This picture was taken on Mt Palomar while Los Angeles was bathed in darkness because of the black-out enforced during World War II. It remains one of the best photographs ever taken.

Edwin Hubble, who had earlier discovered Cepheids in Andromeda, attempted to correlate the recession velocity with distance. He used Cepheids in the close galaxies. In galaxies too far away, he assumed any star he could see was as bright as the brightest star in the Milky Way. If the galaxy was too far away to show any regular stars at all, he used nova or supernova. In the final analysis, where the galaxy was too faint to show any stars at all, he assumed that the biggest member of a group of galaxies was of a similar luminosity to the Milky Way.

What he found was a rough linear relationship, ie the further away the galaxy, the faster it recedes. Given the statistical approximations he had used, this was the best he could hope for. But on the basis of his evidence, Hubble inverted the argument. He announced the relationship between recession velocity — red shift as it is commonly known — and distance, was linear. Mathematically, V = HD. (Where H is the Hubble constant.) Since the red shift is easy to determine from the spectrum of any galaxy, its distance also follows easily.

Although a major shock at the time, in retrospect the recession of the galaxies should have surprised no one. It is a natural consequence of the General Theory of Relativity, and modern cosmologists have argued that it has been implicit in out theories of gravity since Newton's time.

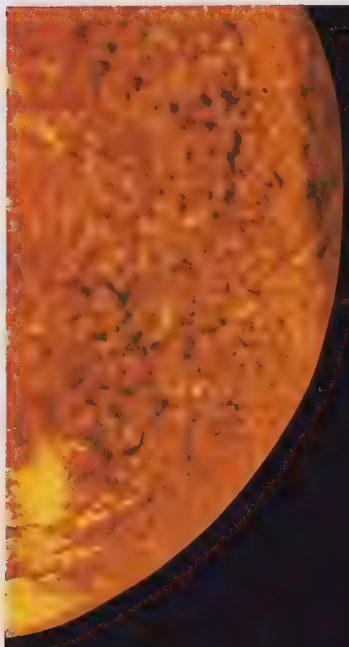
In the years since Hubble, astronomers have done a great deal of work to test Hubble's theory, and to refine the Hubble

Other methods have been refined. A better understanding of nova and even supernova has been pressed into service. As sky surveys have become more comprehensive, statistical analyses have become more sophisticated. Computers — with their ability to record the positions, brightness and recession rates of countless thousands of galaxies — have been an invaluable resource.

The result has been to refine the size of Hubble's constant up and down. Hubble himself believed that value was about 530km per second per megaparsec. (A galaxy 1,000,000 parsecs away is receding from us at a rate of 530km a second.) When the distinction between Cepheids and RR Lyre stars was understood, it was revised down. Today, astronomers believe it is between 50 and 100.

Today, the most distant object known is a Quasar, a very luminous type of galaxy, that is receding from us at 72 per cent of the speed of light. It is thus about 2.2 gigaparsecs (2 200 000 000 parsecs), away.

One of the implications of the Hubble constant is that it puts a bound on the visible universe. Remember that nothing can move faster than the speed of light, so, to determine the distance to the Restaurant at the Edge of the Universe, we need only substitute the speed of light for V in Hubble's equation. It works out at 3 Giga parsecs if H is really 100, twice that, if it's 50. Either way, *space really is big.* ◐



INVESTIGATING THE SUN

A SMALL SPACECRAFT IS NOW MAKING ITS WAY THROUGH THE MILLIONS OF LONELY KILOMETRES BETWEEN JUPITER AND OUR NEAREST STAR — THE SUN. WHEN IT REACHES ITS DESTINATION, IT SHOULD PROVIDE A WEALTH OF SCIENTIFIC INFORMATION ON THE SUN AND ITS EMISSIONS.

by Kate Doolan

Ulysses is the hero of a voyage that takes him beyond The Pillars of Hercules, which at that time was a journey beyond the boundaries of the known world. In October 1990, another Ulysses set out on a rather longer journey, also into the unknown.

The modern Ulysses is a 370kg spacecraft, built by Dornier Aerospace GMBH, Friedrichshafen, Germany, for the European Space Agency. Its mission is to travel to the Sun, via Jupiter, to study the solar polar regions, which are invisible from the Earth, and hence largely unknown to scientists. Ulysses, like its counterpart of old, has been on an equally tortuous journey. And not only in Space. Trouble started well before it was launched.

As originally conceived in the late seventies, the Out of Ecliptic Mission involved twin spacecraft, one each supplied by the US National Space and Aeronautics Administration, (NASA) and the European Space Agency, (ESA). One craft would fly over the solar south pole, pass through the ecliptic and then fly over the solar north pole. The other spacecraft would fly in the opposite direction and give scientists a stereoscopic view of the Sun.

In 1979, the project was renamed 'The International Solar Polar Mission' (ISPM), which NASA officials felt was more indicative of the scientific goals of the project. In 1980, however the ISPM suffered a major setback when NASA announced that due to difficulties with the first flight of the Space Shuttle, the ISPM would be delayed until 1985 at the earliest.

The next year was even worse for the ISPM team. Citing financial difficulties, NASA officials cancelled their spacecraft. This led to the loss of several experiments, and damaged relations with the European Space Agency — which were already troubled by delays to the shuttle.

Under the new arrangement NASA stayed in the project, but only on the strength of using the Space Shuttle to launch the craft. It was also at this time that the launch was again delayed: this time to May 1986.

In 1984, the project was again renamed. With grim irony they named it Ulysses. It was a tribute both to what had gone before, as well as the journey to come.

The spacecraft was transported from Europe to the Kennedy Space Centre in Florida, in 1986, for further testing and in preparation for integration into the shuttle, Challenger.

But on 28 January 1986, the Challenger exploded, killing six astronauts. At first it was thought that the next shuttle mission would go ahead as planned, in May of 1986, but as the investigation progressed, it became clear that the shuttle would be grounded for at least two years.

Ulysses was returned to storage in Europe, while several important decisions were made about its future. Launch was put back to the latter half of 1990 and instead of Ulysses being powered by the liquid-fuelled upper-stage Centaur rocket, it would use the weaker (but safer), Inertial Upper Stage.

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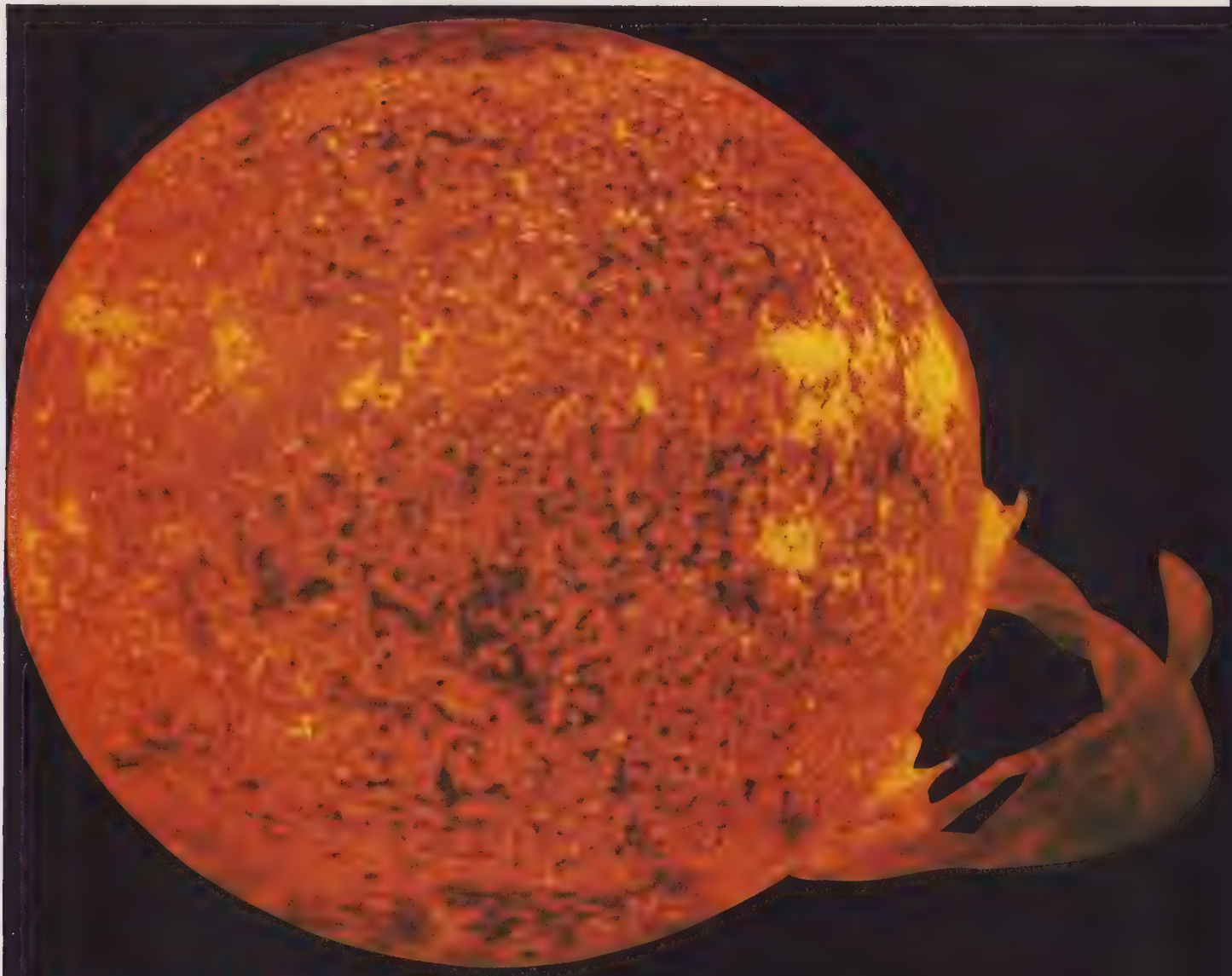

ULYSSES

The long awaited launch of mission STS41 took place on 6th October, when the space shuttle Discovery was launched from the Kennedy Space Centre.

There was one last hurdle. Environmental groups were concerned that should the shuttle explode, the nuclear power plant on board Ulysses would sprinkle southern Florida with radioactive waste.

After a court battle, the launch order was given by the same judge who ruled in a similar case the year before — that being for Galileo.

When it was finally launched, the Ulysses spacecraft comprised a main bus measuring 3.2 metres long, 3.3 metres wide and 2.1 metres high. Ulysses is one of the smallest and lightest payloads ever launched by the Space Shuttle.

Immediately they reached orbit, Discovery's crew, made up of Commander Dick Richards, Pilot Robert Cabana and mission specialists Jim Akers, Bruce Melnick and Bill Shepherd, began preparations to deploy Ulysses. At the beginning of Discovery's fifth orbit, at an altitude of just over three hundred kilometres, Jim Akers at last deployed Ulysses from the shuttle's payload bay.

A 5.6 metre radial magnetometer boom which carries several experimental sensors was deployed, together with several other antenna for radio wave plasma experiments.

One hour later, after Ulysses reached a safe distance from the orbiter, the two solid fuel motors of the Inertial Upper Stage and the Payload Assist Module fired sequentially, sending the spacecraft on a trajectory to the planet Jupiter. Ulysses' initial velocity of more than 70,000km per hour was the fastest departure from Earth orbit of any interplanetary mission.

On arrival at Jupiter on 8th February 1992, Ulysses flew to within 450,000km of Jupiter. The spacecraft accelerated as it neared the planet's north pole region and dived down at an 80 degree angle to the ecliptic plane.

The fly-by of Jupiter, the first since the Voyager encounters of 1979, provided planetary scientists with the opportunity to study the planets magnetosphere and its interaction with the solar wind. It also returned useful information on the Io torus, a sulphur-

laden ring of particles that swarm around the planet after being ejected by volcanoes on the moon, Io.

In June 1994, Ulysses will once again be about one astronomical unit from the sun ie about the same distance from the Sun as the Earth, but low down below the ecliptic plane. It will take about five months to rise up above the plane to repeat the procedure in the Northern hemisphere.

Ulysses' scientific payload comprises nine instruments. The spacecraft's radio will also be used to conduct experiments. The main areas of study will include the Sun itself, its magnetic fields and the streams of particles generated by the Sun — better known as the Solar Wind. Another area of study will be interplanetary space below and above the Sun. It is worth remembering that all our knowledge of the sun comes from the plane of the Earth's orbit, more or less above the solar equator.

The Magnetic Fields experiment will investigate the strength and direction of the Sun's polar magnetic fields — about which very little is known, as they are too difficult to observe from Earth. The investigations will also try to determine the specific regions of the Sun's corona from which solar wind originates.

The Solar and Plasma experiment will investigate the strength and direction of the solar wind, which comprises electrons and charged particles. It will measure these ions and electrons for speed, temperature and density.

The solar wind is expected to be different near the poles, and scientists hope it will be easier to make measurements in those areas rather than near the Sun's equator.

One familiar instrument missing from Ulysses is a television or imaging camera, in contrast to the Voyager spacecraft. It proved too difficult to design an imager within the constraints imposed by the Ulysses bus.

The mission is long and complex. For most of the time, a computer will be in charge. The main computer on the spacecraft is the Data Handling System. This system is responsible for processing commands received from ground controllers. It includes a decoder unit which will process the incoming signals from the radio receiver and pass commands to the other systems. The system is also responsible for managing all the data from each of the spacecraft's scientific instruments.

Remote units will handle input and output to and from the spacecraft's systems and the data storage unit, which comprises two tape recorders. Each of the recorders can store 45.8 million bits of data, which represents from 16 to 64 hours of data-taking, depending on how data is sampled.

The attitude and orbit control system is responsible for determining Ulysses' attitude in space, as well as firing thrusters to control the attitude and spin rate of the spacecraft.

Apart from all this, Ulysses has a redundant computer, sun sensors and the Reaction Control System, which has eight thrusters and is powered by 35kg of a propellant called hydrazine, stored in a single diaphragm tank mounted on the spacecraft's spin axis.

Ulysses' power source is the Radio-isotope Thermoelectrical Generator (RTG), similar to those used on Voyager and Galileo, as well as other deep space missions. RTGs are required for these missions as solar arrays would be too large and too heavy to launch by any available rocket. In the RTG, heat is produced by the decay of Plutonium-238, which is then converted into electricity by thermocouples.

Ulysses' communication systems include two S-band receivers, two five watt S-band transmitters, two 20 watt X-band transmitters, two small low gain antennas and the high gain antenna.

The high gain antenna is used to transmit in either the S or X band as well as receive in the S band. The low gain antennas are used to both receive and transmit in the S band.

Tracking and data acquisition on the Ulysses mission is provided by NASA's Deep Space Network, (DSN). During most of Ulysses' mission, the DSN will be in contact eight hours a day. Currently, the spacecraft is recording all its engineering and scientific data during the 16 hours it is out of contact. During the eight hours of contact, the spacecraft transmits the stored data from its tape recorders.

The DSN has complexes in the US, Spain and at Tidbinbilla in the ACT, which are spaced 120 degrees apart in longitude, so as the Earth

space since Voyager took his picture in 1979.

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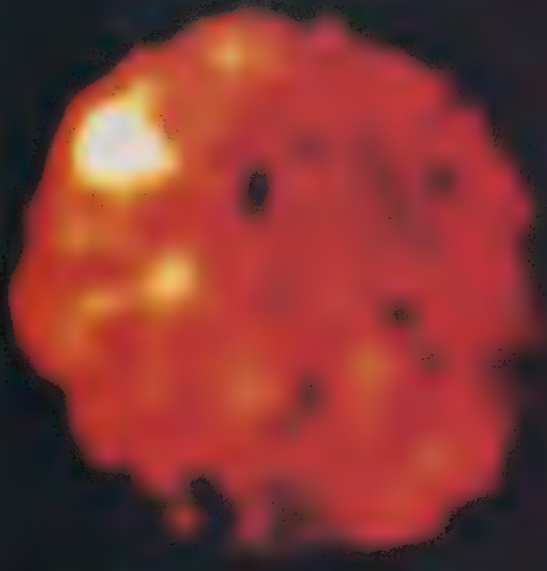
rotates, a given spacecraft will always be in view of one of the DSN stations.

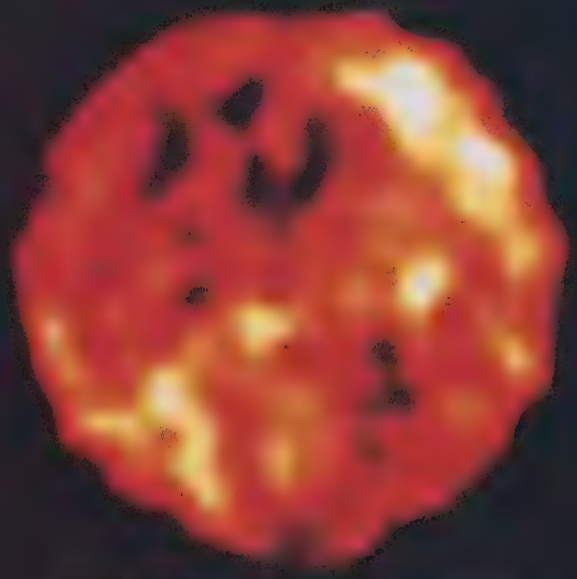
Each station is equipped with a variety of dishes. The largest is 70 metres in diameter. The mission specifications called for a 30 metre antenna to be used to transmit and receive from Ulysses in order to conserve antenna coverage during busy periods at the DSN.

However, Ulysses' ground controllers can call on the 70 metre dish antenna to communicate with the spacecraft. The larger antennas permit a higher data rate, so they are scheduled when high data volumes are expected.

Mosaic of Voyager photographs of Io, the most active volcanic body in the solar system. It is so active that it can expel particles at its escape velocity. Ulysses discovered that these are marshalled into a ring, or torus, by Jupiter's magnetic field.



HST View in Visible



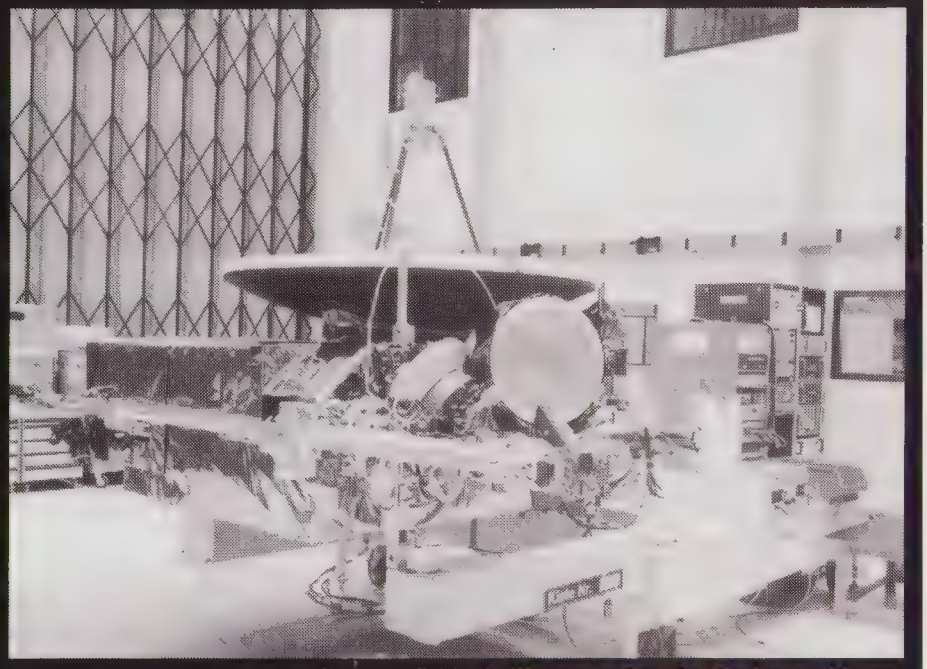
HST View in Ultraviolet

Voyager at HST Resolution

Voyager at Closest Encounter

Ulysses is one of the smallest and lightest payloads ever launched by the Space Shuttle.

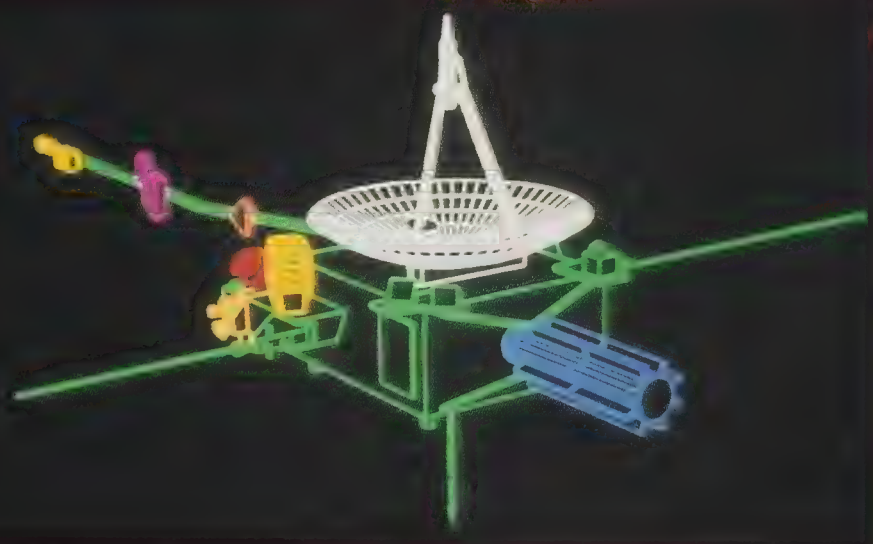
Data received from Ulysses is transmitted to the Jet Propulsion Laboratory in Pasadena, California, by a combination of satellites, ground microwave links and land lines, and from there to ESA headquarters in Europe.



Ulysses undergoing final assembly at Dornier Aerospace in Germany where it was manufactured

Its mission is to travel to the Sun, via Jupiter, to study the solar polar regions ...

The trajectory of the Ulysses mission. Existing rockets would have not been powerful enough to send Ulysses into an orbit at 90 degrees to the Earth's. So the mission relied on a gravity assist from Jupiter, the most massive planet in the solar system. As an added bonus, Ulysses was able to research the magnetic fields of Jupiter space.



A schematic of Ulysses in flight configuration.

There is no doubt the science return from the mission would have been richer had the original plan, using two spacecraft, been adhered to. Nevertheless, Ulysses is in good health, and looks set to add significantly to our knowledge of the Sun.

THE TROUBLE WITH H

NASA

AFTER MORE THAN ITS SHARE OF DELAYS AND HITCHES, THE HUBBLE SPACE TELESCOPE WAS PUT INTO ORBIT IN 1990. ONCE IN ORBIT, IT WAS FOUND THAT ITS PRECISION OPTICS WERE FUNDAMENTALLY FLAWED. OTHER PROBLEMS FOLLOWED. BUT A FIX LATER THIS YEAR SHOULD PRODUCE 95 PER CENT OF THE INFORMATION HUBBLE WAS ORIGINALLY GOING TO YIELD.

HUBBLE

by
Kate Doolan
and
Jon Fairall

THERE IS LITTLE DOUBT THE Hubble Space Telescope is NASA's biggest public relations disaster. While the Challenger disaster cost infinitely more, there was at least the nobility of sacrifice to compensate for the loss of an orbiter and its crew. The HST has left NASA looking just incompetent.

So a lot will be riding on a Space Shuttle mission later this year to fix most of Hubble's problems. The fix will not be total, but it will restore most of the functionality of the telescope.

As with most American space projects since the late 60s, the Hubble Space telescope has been a political football. It suffered cuts, alterations, changes to schedules and all the usual gamut of design modifications. It was also caught by the Challenger accident in 1986. The result is that, when it was launched in 1990, it was nearly 10 years behind schedule and millions of dollars over budget.

The idea of having a spacebound telescope is not a recent one. In the 30s, German rocket scientist and pioneer Herman Oberth suggested that having a large telescope in Earth orbit would give astronomers an unobstructed view of the universe as a whole and would provide new opportunities in solving the answers to astronomy's greatest questions.

In 1946, Princeton University astronomer Lyman Spitzer advocated construction of a large space telescope with an aperture of 3m in Earth orbit at an altitude of 400km. Spitzer also envisioned that the telescope would be in constant, 24 hour-a-day, use by both professional and amateur astronomers.

In the glory days of NASA in the 60s, the space telescope was a frequent item on scientists' agendas but for the most part, remained a discussion piece. It was not until 1969 that the Space Science Board of the National Academy of Sciences called for a large telescope to be placed in orbit by the late 70s.

Following the lunar landing in July 1969, space lost its allure for the US public. With its popularity went the money. NASA's budgets were slashed. Its senior executives were then placed in the unaccustomed position of fighting for funds. They also had to justify the economics of future projects. This policy had dire effects on the fledgling space shuttle program and was to prove disastrous in later years, to both manned spaceflight and space science.

In 1973, the US National Academy of Sciences released a study which reviewed the priorities and needs of astronomy for the remainder of that decade, and again recommended a large orbital optical telescope. At the same time, NASA convened several small teams of astronomers to provide guidance for groups at the Goddard and Marshall Space Flight Centres who were conducting feasibility studies for space telescopes.

In 1973 NASA established a scientific and engineering steering committee to determine scientific objectives for the space telescope. In 1975, the European Space Agency (ESA), became involved with the project and agreed to pay 15 per cent of the space telescope's costs. ESA also agreed to build the solar arrays and one of the scientific instruments, and to contribute manpower to the project. In return ESA got 15 per cent of observing time and access to data from other scientific instruments.

After a somewhat bitter fight to gain funding from Congress, in which scientists became politically active and lobbied individual congressman and senators, Congress finally approved funding for the Large Space Telescope in 1978. However, along the way, the

Hubble deployed. This close up view shows the solar panels that made the telescope vibrate wildly.

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telescope's aperture was reduced to 2.4m and the 'Large' dropped from the title.

Named after the eminent American astronomer Edwin Hubble (1889-1953), who discovered the expansion of the universe and the nature of galaxies, the Hubble Telescope was designed as the first long-term repairable space observatory. It is designed to last 15 years.

The telescope is 13 metres long and has a mass of 11,600kg. It orbits the earth at 607km, at an inclination of 20.5 degrees. The HST has two mirrors, an objective which is 2.4m in diameter and a secondary which is 300mm across.

The major elements of the Hubble Space Telescope are the Optical Telescope Assembly (OTA), the six scientific instruments — the European designed Faint Object Camera, the Wide Field/Planetary Camera, the Faint Object Spectrograph, the High Speed Photometer, and the Goddard High Resolution Spectrograph — as well as the Support Systems Module which houses the electronics, electrical support systems and scientific instruments.

The Optical Telescope Assembly consists of the primary and secondary mirrors, support trusses and the focal plane structure. Incoming light travels down a tubular beam. It is then reflected by the primary mirror and travels to the secondary mirror. After that the light is reflected by the secondary mirror through a hole in the primary mirror to the focal plane, behind the primary. This is where the scientific instruments receive and process it.

NASA

The Hubble Space Telescope is moved to the thermal vacuum chamber at Hughes Missile and Space Company in Los Angeles. The highly reflective material on the outside is designed to keep the temperature more even.

The HST is powered by two solar arrays located on either side of the telescope. Each of these arrays contains 48 solar cells which convert the Sun's energy to electrical power, which is used to power all the telescope systems. When the Sun is eclipsed by the Earth, power is stored in six nickel-hydrogen batteries.

The Wide Field/Planetary Camera has two purposes. In the wide field mode, its field of view will permit it to take images of extended objects, hundreds of distant galaxies in a cluster, for instance. In the planetary mode, it will provide photographs of all the planets in our solar system — except Mercury, which is too close to the Sun for the HST to point at.

The Faint Object Camera (FOC), was designed to extend the reach of the Hubble Space Telescope to the greatest possible distance and produce the sharpest images. It is designed to intensify images 100,000 times.

The High Speed Photometer (HSP), is a simple but accurate light meter that measures the magnitude of objects being observed as well as any variations in that brightness with time, in both the visible and ultra-violet spectrums. One of its most important functions is to look for fluctuations in light from stars. This is particularly interesting in the study of binary and variable stars. It is also extremely useful in providing precise measurements on stellar magnitudes.

The Hubble Space Telescope has two spectrographs aboard, which are not cameras as such, but take a chemical fingerprint of an object being observed. In fact, they separate the radiation received from an object according to wavelength. Each chemical element produces its own individual pattern, so when the spectrum is analysed, scientists know what element and molecules are contained in the object being observed.

The Goddard High Resolution Spectrograph is the only scientific instrument on the HST dedicated to studies of ultra-violet light. The 'high resolution' in the instrument's name refers to the ability to study the spectra in great detail, resolving extremely fine lines very close together.

The Faint Object Spectrograph (FOS), is used to analyse properties of faint objects in both visible and ultra-violet light. The FOS is equipped with devices that block out light at the centre of an image being viewed, so that the much fainter light around a bright object can be observed. One important area of study for the FOS is the examination of comets before they reach the Sun.

Though not considered as scientific instruments, the three guidance sensors serve two important functions. Two of the sensors will each lock onto a reference star, to point the HST at a precise position in the sky, and hold it there with a

remarkable degree of accuracy. The third sensor, in addition to serving as a backup, can be used for astrometry — the science of measuring angles between astronomical objects.

Following deployment from the space shuttle, Discovery, in April 1990, the HST began a period of checks designed to lead to full time operations in September of that year. As it turned out, it was anything but routine. Engineers uncovered one problem after another.

The first problem manifested itself in the deployment of the High Gain antenna. Eventually this was solved. However, a problem in the solar panels was not. On most orbits, the Sun is occulted by the Earth, only 400km below. When this happens, the HST, like any other spacecraft, goes through thermal shock. You can hear the same thing happen to any large tin roof on a sunny day when the sun ducks behind a passing cloud. Spacecraft are particularly vulnerable to heat gain and loss because there is no atmosphere to absorb the effect, as happens on Earth. Nevertheless, this is a well understood problem.

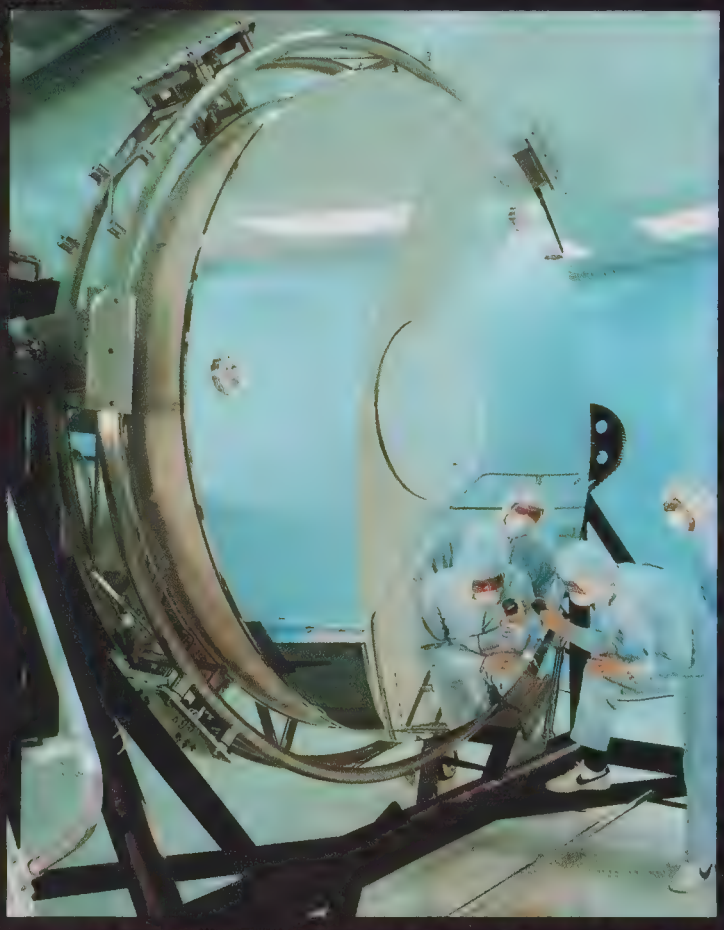
However, the designers of the solar cells — British Aerospace — apparently did not understand the problem as well as they should. Every time the HST hits the Earth's shadow, it vibrates violently from side-to-side as the contracting solar panels pull it one way, then the other. The problem has been fixed to a certain extend by the use of clever software. The repair mission later this year will carry new solar panels intended to fix the problem completely.

Meanwhile, even bigger and more fundamental trouble was looming. In June 1990, NASA officials announced that it was impossible to bring images into focus. It turned out that the mirror — "the most optically perfect mirror ever made" — was perfectly in error by about half a millimetre. It might appear a tiny amount, but in optical terms, where tolerances are measured in wavelengths of light, it is a major flaw.

The result of this problem has been catastrophic. While some of the instruments are unaffected, the faint object camera and the wide field camera are both crippled. To a certain extent, the problem can be countered with clever computer processing. Scientists in the Space Telescope Institute have spend a great deal of time and energy working on deconvolution — a computer process by which much of the image quality can be restored.

It is possible because spherical aberration is actually quite a simple optical problem, and simply cured. It implies that it is impossible to bring all the light to a clear focus at one point. The result is a smeared image. While all the light should converge on one spot, it now covers a much wider area. However, scientists at the Institute have determined very accurately how this occurs, and have been able to remove the smear and put it back into the point, thus improving the ratio between the brightest and darkest parts of the image.

NASA

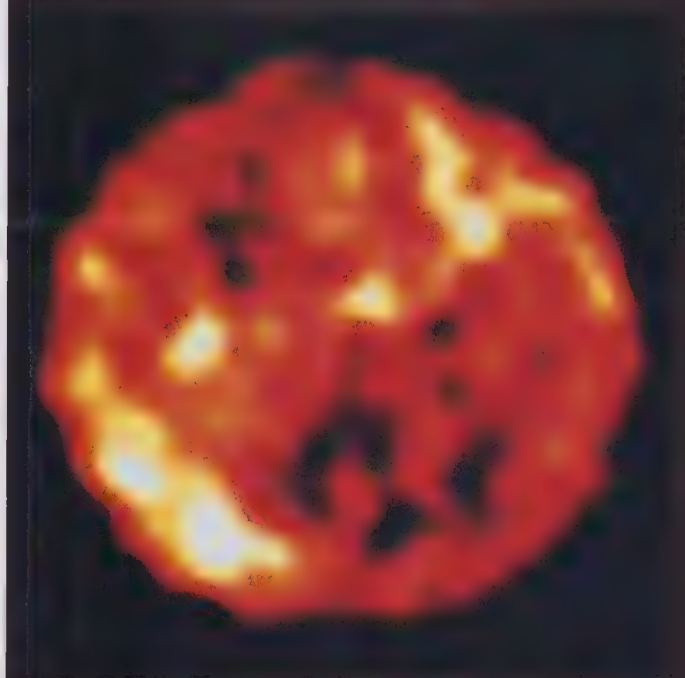


The objective mirror of the Hubble Space Telescope. Apart from anything else, it was a public relations debacle for NASA. The photo caption from NASA begins, "This is the most perfect mirror ever made ...". Most bureaucracies could shrug this off. However, NASA is different. It depends for its existence on being able to convince US tax-payers that money spent on space is worthwhile.

The result is that Hubble is now producing images better that those from the biggest ground-based imagers. Problems remain, nevertheless. It is still impossible to investigate stars close together. The computer program falls over whenever the stellar images are smeared across one another, and it is impossible to recover the original image. This problem is especially critical. One of the main objectives of the HST — certainly its main selling point to the American people — was that it might be able to answer fundamental questions about cosmology. Unfortunately, this involved doing things like looking at individual stars in very faint galaxies, exactly where stars tend to be bunched tightly together. This is quite impossible, and remains so in spite of clever processing.

A third problem with the telescope has recently emerged. Its gyros are failing. It is quite practical, and routinely done, to design gyros for spacecraft that will easily outlive the other systems on board. However, three of the six gyros necessary for attitude control of the craft have now failed. Because of in-built redundancy the mission is not jeopardised, but it will be if any more fail.

It is one of the cruel ironies of the HST that all its failures have been in well understood, almost trivial technologies. People have been making gyros and solar panels for years without problem. Grinding a mirror to the right shape is routine.



European Space Agency

The first ultra-violet image of the Jovian moon, Io, taken with the HST's Faint Object Camera. It seems to demonstrate that apart from hot spots generated by volcanic activity, the surface of Io is covered with a sulphur dioxide frost.

The difficult things on Hubble — like the fine guidance system, for instance, are operating perfectly.

The difficult things on Hubble — like the fine guidance system, for instance, are operating perfectly.

A repair mission is planned for late 1993. New gyros will be fitted, as will new solar panels. The optical problem will be almost completely corrected by removing one of the instruments and replacing it with a package called Costar. It consists of a set of mirrors that can be moved into the optical path on robot arms. These mirrors are designed to compensate for the spherical aberration and will be changed to suit each instrument as required. If it all goes according to plan, the HST will function at 95 per cent of its designed capacity, perhaps more in practice. Scientists at the Institute say that because of all the image enhancement work done on the mirror, they have advanced the science considerably. When the corrective optics are fitted, computer enhancement will continue, so that images will be considerably refined.

It remains to be seen however, whether Hubble will really live up to its advertising. The central aim of the HST was to refine the values of the Hubble constant (*see the article on distance scales elsewhere in this issue*), by looking for very distant Cepheid variable stars. To do so, the faint object camera must be made to work almost perfectly.

But now a new problem has emerged. It turns out that the focal length of the telescope varies with its temperature. This effect is masked by the spherical aberration, and so had only been detected quite recently.

As of February 1993, scientists at the Space Telescope Institute were battling to understand the problem. Hubble was specifically designed so that its focal length would be immune to temperature variations.

The problem has major implications for the success of Costar however, as its corrective optics will amplify the problem. It turns out that the problem could be corrected using Costar by continuously repositioning the mirrors. But it has not been designed for this, and would need to be rebuilt, with all the attendant delays, if this was a likely scenario.

If all goes according to plan, in December, two astronauts will spend hours outside the Shuttle repairing the HST. It will be dangerous, difficult work. Cosmologists around the world are hoping they will be successful. ◐

Space Science Institute

It is still possible to do first class science with the HST. This picture shows a striking dark 'X' against the core of M51, a nearby spiral galaxy. The 'X' is due to dust, and marks the exact position of a black hole with mass about 1 million solar masses. The darker bar is probably an edge-on disk, 100 light years in diameter.

VIRTUAL ASTRONOMY?

NASA can't take you but perhaps your personal computer can ...

If ever a company's name could be said to give the game away, then Virtual Reality Laboratories, Inc., must be up there with United Distillers, Tip Top Bakeries, and Pizza Hut. Anyone might make a reasonable guess about the nature of the products from these four.

VRLI offers a number of products appealing to those with an interest in astronomy and space exploration.

Of course, such people must have access to a personal computer, whether it be IBM-compatible, Macintosh or Amiga. A CD-ROM drive would be nice but not essential.

The California-based company has Arthur C. Clarke onside, quoting his approval in its literature. What can you expect from the software?

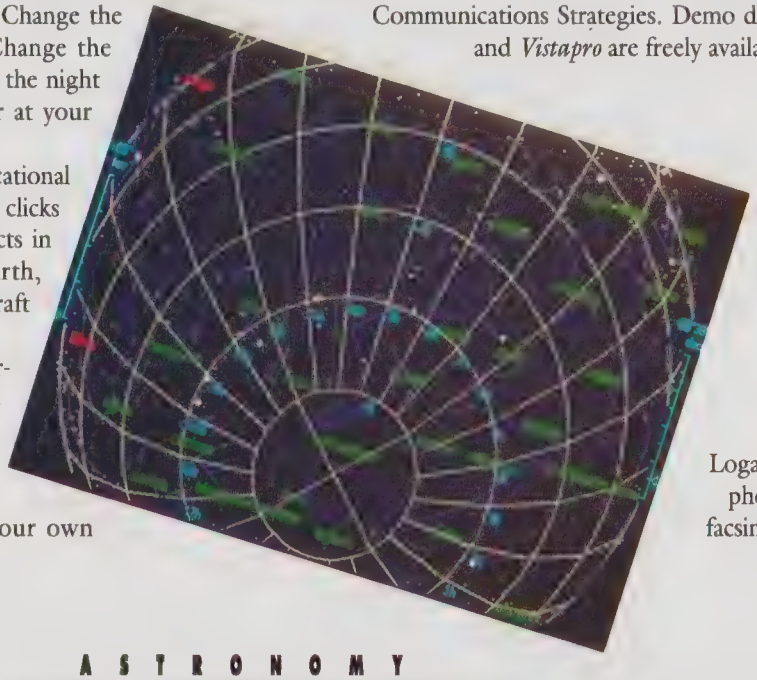
Distant Suns, (available for IBM PC running Windows, Amiga, and on CD-ROM for Mac or IBM), promises a virtual reality observatory anywhere on earth, at any time from 4173 BC to 10,000 AD. So you can configure the software to your location, the current date and time and your computer will display the sky as it appears overhead were you to step outside your door. Change the location data and get a different view. Change the date and time for another. Tempted to see the night sky over Bethlehem 2,000 years ago? Or at your time, date and place of birth. Go ahead.

These are neat, entertaining and educational tricks, but not the end of the story. Mouse clicks will provide more information about objects in the sky, such as name, distance from Earth, constellation outlines, and NASA spacecraft photographs of planets.

The planetarium clock can be accelerated so that you may observe the planets traversing the heavens. You can view an eclipse or observe a comet's transit. And if you have the equipment, you can customise the program with your own scanned images associating them with particular objects in the sky.

Vistapro is based on US Geological Survey and NASA data. For the astronomically inclined, virtual reality access to Olympus Mons on Mars is included, with additional landscape sets of the equatorial region of Mars available.

On CD-ROM you can also get *Mars Explorer*, and titles such as *Our Solar System*, *Space Series — Apollo*, *Space Series — Shuttle*, *Space and Science Sampler*, also appear in the catalogue available on request from the Australian distributor, Communications Strategies. Demo disks of *Distant Suns* and *Vistapro* are freely available on request. ◐



You can contact Communications Strategies at PO Box 3043, Loganholme, Qld 4129: phone (07) 841 1055; facsimile (07) 841 1637.

DEEP SPACE PHOTOGRAPHY

DAVID MALIN

EXPLAINS NEW TECHNIQUES OF EXPLORING DEEP SPACE.

THE SWEEPING ARC OF THE NIGHT sky must have intrigued mankind since the first ancient cave dwellers lifted their eyes above the camp fire and wondered. Wonder naturally gives rise to curiosity which in turn soon leads to a search for an explanation. But despite centuries of speculation, it is only in the last few decades we have begun to understand the stars and the enormous stellar system in which we live. The science and art of photography have been essential to this discovery.

Unfortunately, very few of us are now familiar with the starry sky. Unlike our ancestors, our nights are spent in brightly-lit suburbs, curled up in front of the television. We choose to shut out the dark and in doing so we miss the nightly spectacle that was familiar to everyone before the electric light. However, the science that brought us light and television also led to photography, and it is photography which enables us to recapture the sky and show it in a way our ancestors could not have imagined. ►►►

Figure 8: Colour negative film was used for one of the first colour pictures to be made on the UK Schmidt. The three colour process shows that this part of the sky is filled with colourful nebulosity, too faint and of too low contrast to be recorded on ordinary colour film. The region covers the region around Antares (upper left), and includes the blue reflection nebula associated with Rho Ophiuchus on the right of the picture.

But what can be new about photographing the sky? Astronomers have been doing it for over a hundred years. Well, there is something new. There is colour. For the first time, there are photographic processes that can show the true colours of the faintest stars and galaxies, colours that reveal much more about them than can ever be seen in black and white.

But because the light from these objects is so feeble special photographic processes are needed to reveal them. This is because ordinary colour film simply is not good enough for the job. Despite today's high speed films, the objects of interest to astronomers are just too faint to be photographed against the ever-present glow of the night sky, even with the most powerful telescopes.

The problem is that 'everyday' films are just that, products designed for short exposures using reflected sunlight, which has roughly equal amounts of energy at all visible wavelengths. The distant objects of the night sky emit their own light, often quite unlike the thermal spectrum of the Sun, and their faintness forces long exposure; both are conditions that colour films handle badly.

ADDITIVE COLOUR PHOTOGRAPHY

To overcome these problems we have revived an old way of making colour pictures by using three separate, black and white photographs taken in red, green and blue light and combining them into a colour picture in the darkroom. The difference is that this old method uses the special modern plates astronomers prefer for their black and white pictures, and a series of new processes specially tailored for the unusual imaging requirements of astronomy. The monochrome photographic emulsions intended for astronomical photography are designed to be efficient during the long exposures that are necessary and can be speeded up even more by bizarre hyper-sensitising techniques. These processes often involve baking the plate in nitrogen gas and soaking it in hydrogen just before use.

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As well as being responsive to gas treatment, the plates must have unusually high contrast to cope with another problem faced by astronomical photographers. Even in the darkest places, such as Siding Spring Observatory in outback New South Wales, the sky is never completely black because energetic particles from the Sun make the upper atmosphere glow faintly, even during the night. This uniform foreground radiation, combined with the light from unresolved stars and galaxies, and light scattered by dust, both near and far contributes to the night sky airglow, and eventually limits the exposure by gradually fogging the plate.

To accommodate other astronomical requirements, a range of emulsions is available, each with a different spectral response. These can be used with colour filters to define three colour bands so that together the three plates have a fairly uniform response across the whole of the visible spectrum. Colour pictures are created from the black and white negatives by making three carefully matched positive film copies. At this stage several image enhancement techniques, such as unsharp-masking or contrast enhancement can be used to reveal ever fainter objects or to enhance fine detail. Each of the resulting positives contains either the blue, green or red information about the astronomical object.

The information in the positives is recombined into a single colour picture by projecting each of the images, one at a time, through red, green or blue filters as appropriate, onto positive-working colour paper or onto sheet colour negative film. This is most conveniently done by using an enlarger, but the images must be in perfect register for the technique to work well and the three separate exposures must be adjusted to allow for the colour of the enlarger lamp and to obtain a correct colour balance.

Making colour pictures from black and white positives was the earliest method to be used for making colour pictures, but it was soon found to be inconvenient because three separate pictures had to be taken. This meant that there were always problems with movement of the subject and adding the images together later also complicated things. But movement of the stars is not a problem in astronomy. They re-appear, night after night in the same place relative to each other, and the three pictures needed to make a colour shot can be taken years apart. Having the colour information stored on three black and white negatives also offers other advantages.

Because the black and white plates are treated separately until the images are recombined into a colour image, elegant image enhancement techniques can be applied to them in a way that is impossible for colour films. A full description of these processes can be somewhat technical but the outline below gives the flavour of what has become a fully integrated system of photography.

Illustrated examples show the power and versatility of these basically simple processes. They have been used with plates from the Anglo-Australian Telescope (AAT), and UK Schmidt Telescope (UKST), to produce some stunning pictures. Together these techniques and the big new telescopes in Australia have transformed the astronomical landscape, at least in the southern hemisphere, which for the first time can be seen in its true colours.

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Figure 1: The majestic Catherine wheel of Messier 83 is a spiral system believed to be very similar to the Milky Way. If we could leave our Galaxy and travel 27 million light years away before turning and looking back, this is what we would see. The galaxy is made of billions of stars, but only the very brightest can be seen as individuals. These are the blue giant stars that populate the spiral arms. They are associated with clouds of gas and dust, here and there lit up by the hot stars into pink nebulae, just like the Orion Nebula that is nearby in our own Galaxy.

MATHEMATICS

1: Multiplication

The build-up of fog from the unavoidable night sky airglow eventually limits the amount of exposure that can be given. Well aware of this, the experienced astronomical photographer will carefully control the exposure of a deep plate so that the minimum density (blackening on development), obtained is one where the emulsion has maximum contrast. Faint images are therefore recorded at a density very slightly greater than the uniform sky fog and the silver particles which make up the image tend to be in the upper part of the developed layer. If a low density contact copy of a developed plate is made with a diffuse light source on to high contrast film, the near-surface grains of the original are recorded on the copy with greatly increased apparent size, multiplying their effect in the final image.

High contrast prints made from this positive reveal extended features where only one in 200 of the original photons recorded by the plate are 'signal' photons from the object of interest, the rest are the unwanted 'noise' from the night sky. These are some of the faintest astronomical images ever seen.

The two examples in Figure 4 show (a) the appearance of an original UK Schmidt plate of a faint galaxy (Malin 1) in the direction of the Virgo cluster and (b) the same plate after photographic amplification. This insignificant smudge turns out to a distant, giant galaxy that for some reason is very inefficient at producing stars. It is bigger and much more massive than the Milky Way, but many fewer stars.

2: Addition

Even with photographic amplification, there are objects that are too faint to be seen against the grainy background of the developed negative. This is particularly true where images are small. Fortunately, repeat exposures record the same stars and galaxies year after year, but each of the negatives has different granularity. Combining the data from several exposures therefore emphasises the image while smoothing out the granular structure. This gives a real improvement in the 'signal to noise ratio' and is clearly seen in the pair of greatly enlarged images of a random star field (Figure 5), for which we happen to have a large number of plates.

... there are objects that are too faint to be seen ...

Image (a) was made from a greatly enlarged photo-amplified derivative of a single exposure, while image (b) combines the information on 17 separate sky-limited exposures of the same field, made on the same telescope over many years. The possibility of combining several images in register leads naturally to a system of colour photography. The faintest images on the combined print are at about magnitude 24.5, remarkably faint for a 1.2m telescope, (the UK Schmidt).

3: Division

In a conventional negative on black and white film, a grade of printing paper can usually be found which will produce a print containing all the detail on the negative. In astronomy, not only are the negatives much more contrasty than normal, but the objects themselves cover a much wider brightness range, so normal printing is often not possible. Fortunately, much of the developed density in the image is low frequency information (ie, course detail), of little pictorial interest. It can be removed from the negative by printing it through a positive unsharp mask to reveal and enhance the fine detail, see Figure 6.

A blurred positive contact film copy of the original glass negative (or film mounted on glass), is made by contact copying the negative on to film so that the original emulsion and film copy are separated by the thickness of the glass. A diffuse light source is used to make the exposure, and the film developed in a soft-working developer.

When the mask has been processed, it is replaced in position on the back of the original and a normal, emulsion-to-emulsion copy is made on another piece of film, through the positive mask. The blurred positive cancels the large scale structures in the negative, leaving the fine detail untouched.

Careful control of exposure and processing is needed for success but the improvement in the visibility of detail is quite dramatic. The Trapezium stars in the Orion nebula are always difficult to photograph against their nebulous background (Figure 6a), but copying the negative through an unsharp mask (Figure 6b), greatly improves their visibility and that of very faint stars close to the bright ones, (Figure 6c). This picture was a one minute exposure at the Cassegrain focus of the AAT where the telescope acts as a photographic objective with a focal length of 31 metres working at F/8.

4: Subtraction

If two similar plates of the same object exist they can be used to reveal any differences between them. To do this, a contact positive copy of one plate is located in register on a different negative of the same field. Any difference between them is immediately apparent and it can be recorded (usually by projection in an enlarger), on to another piece of film or paper.

A recent example of the value of this technique is shown, where a plate of the light echo surrounding supernova 1987A has been subtracted from an identical plate of the region taken several years before the star exploded, (Figure 7a). The two concentric circles are the expanding light sphere from the supernova scattered from two thin sheets of interstellar dust crossing our line of sight to the distant star. However, they are very faint and are mixed up with the nebulosity and myriads of stars which fill the field. They are hardly visible against this complex background on the original plate, (Figure 7b).

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Figure 3: The Orion Nebula is one of the best-known nebulae in the sky. It is so bright it can be seen without a telescope and was the first to be photographed, in 1883. The colour pictures gives us a ringside seat to the violent events that surround the birth of stars. At the brilliant heart of the nebula, the hot, newly-formed stars that have appeared there cause the nebula to glow and the colours that they produce tell astronomers about the composition of the gas itself. The three plates that produced this image were copied through an unsharp mask to reveal structure buried in the brightest part of the nebula.

COLOUR PICTURES OF FAINT OBJECTS

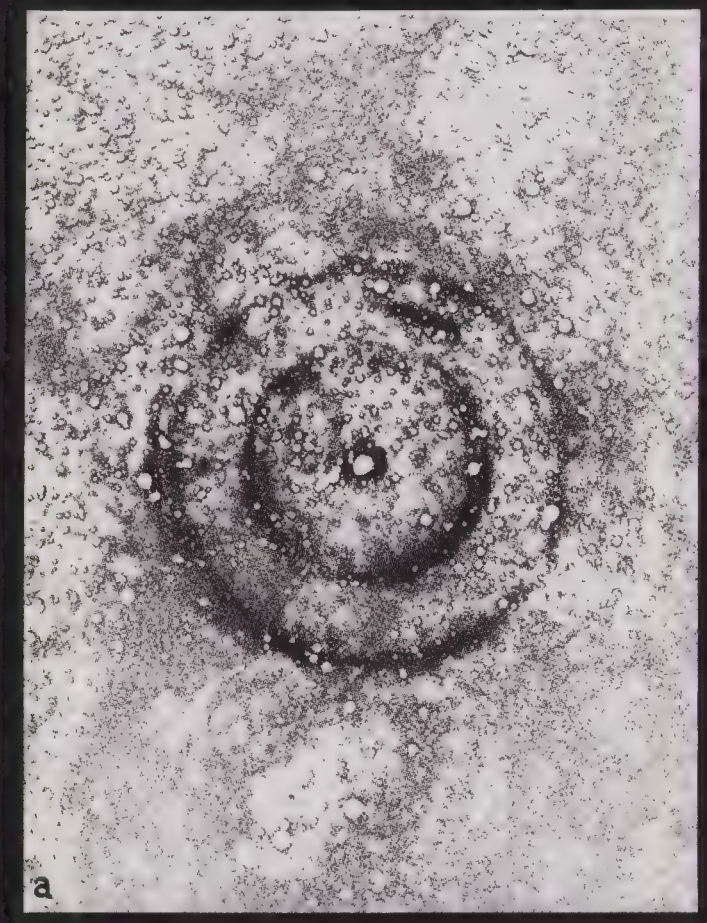
Experiments with ordinary colour films at both the AAT and the UK Schmidt gave good results for only a few relatively bright objects. Fainter objects were hardly visible above the night sky airglow, which explains why the special emulsions designed for astronomical use must be so contrasty.

Because, unlike colour film, these black and white emulsions can be readily hyper-sensitised, a three colour photographic system has been devised to take advantage of these properties. The method can include all the image enhancement processes mentioned above.

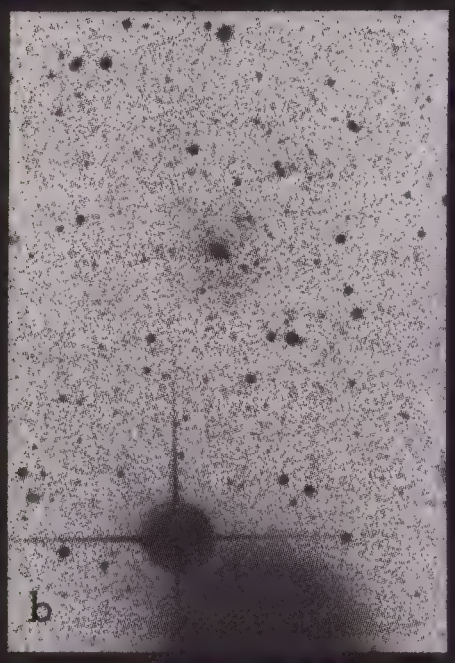
The value of this approach is demonstrated if we compare two identical fields of the spectacular nebulosities associated with Antares and Rho Ophiuchus. The best result we could obtain from a 60 minute UK Schmidt exposure on colour film, shows hardly any nebulosity, while Figure 8 (on page 32), is the same field, but photographed separately on three black and white plates and copied with photographic amplification before being combined into a colour image.

The remainder of the colour pictures reproduced in these pages were made from three black and white plates and incorporate one or more of the image enhancement techniques mentioned above. More technical details and many more examples appear in *Colours of the Stars* by David Malin and Paul Murdin, published by the Cambridge University Press, 1984.

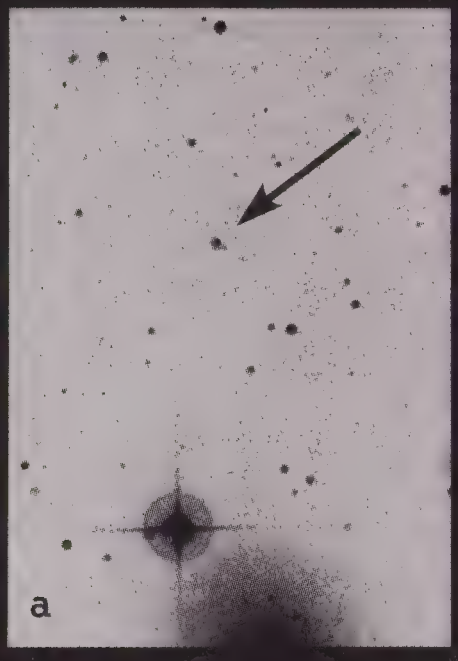
Figure 2: The blue light that is scattered by the dusty particles is itself sometimes bright enough to be seen, but naturally can only be identified on colour photographs. Such a cloud surrounds the beautiful red of the Trifid Nebula. The vivid red colour is the glow of hydrogen gas excited by energetic ultraviolet light from a compact cluster of stars hidden at the centre of the nebula, while the blue is light from the same stars, but scattered by dust and gas. The colour is typical of a reflection nebula.†

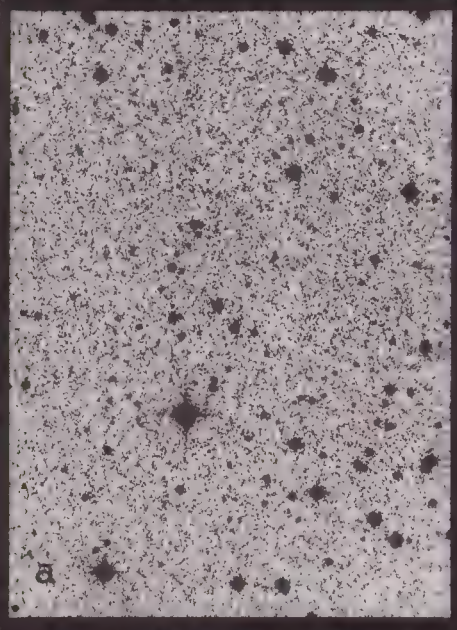


(Left) Figure 7: The light echo from supernova 1987a is revealed by subtracting a recent plate from one that was taken before the star exploded, (a). Without the subtraction (b), the echo is almost lost in the nebulosity which fills this part of the sky.

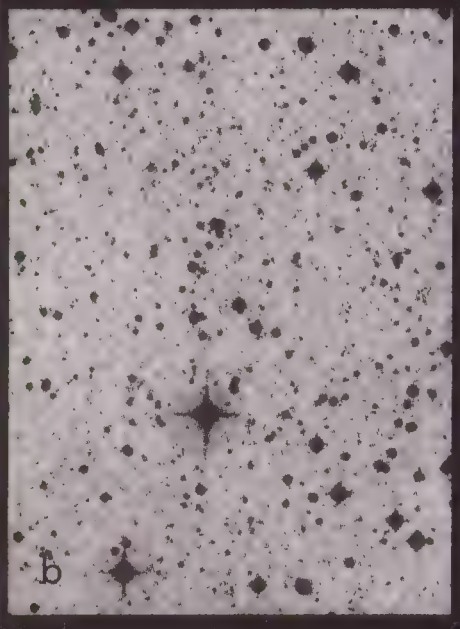


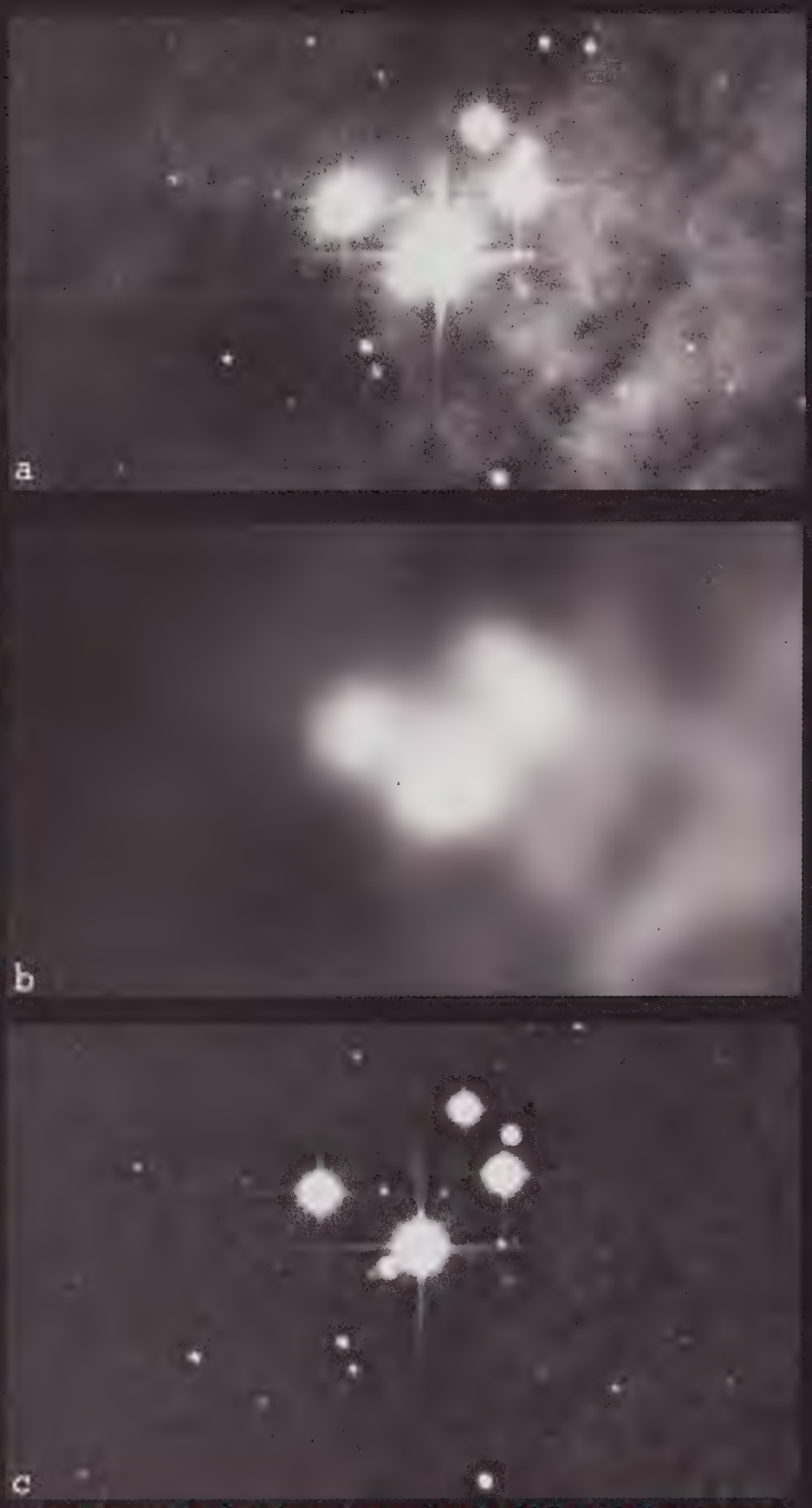
(Above and below) Figure 8: A distant, huge and very faint galaxy in Virgo (arrowed), discovered by photographic amplification of UK Schmidt plates. The two pictures are derived from the same plate and show the faint structures revealed by the process.





(Above and below) Figure 5: These two pictures are of the same field photographed by the UK Schmidt telescope. The picture above (a), was made from a single plate, greatly enlarged. Note in (b) the improvement in visibility obtained by adding together images of the same field from 17 different plates.



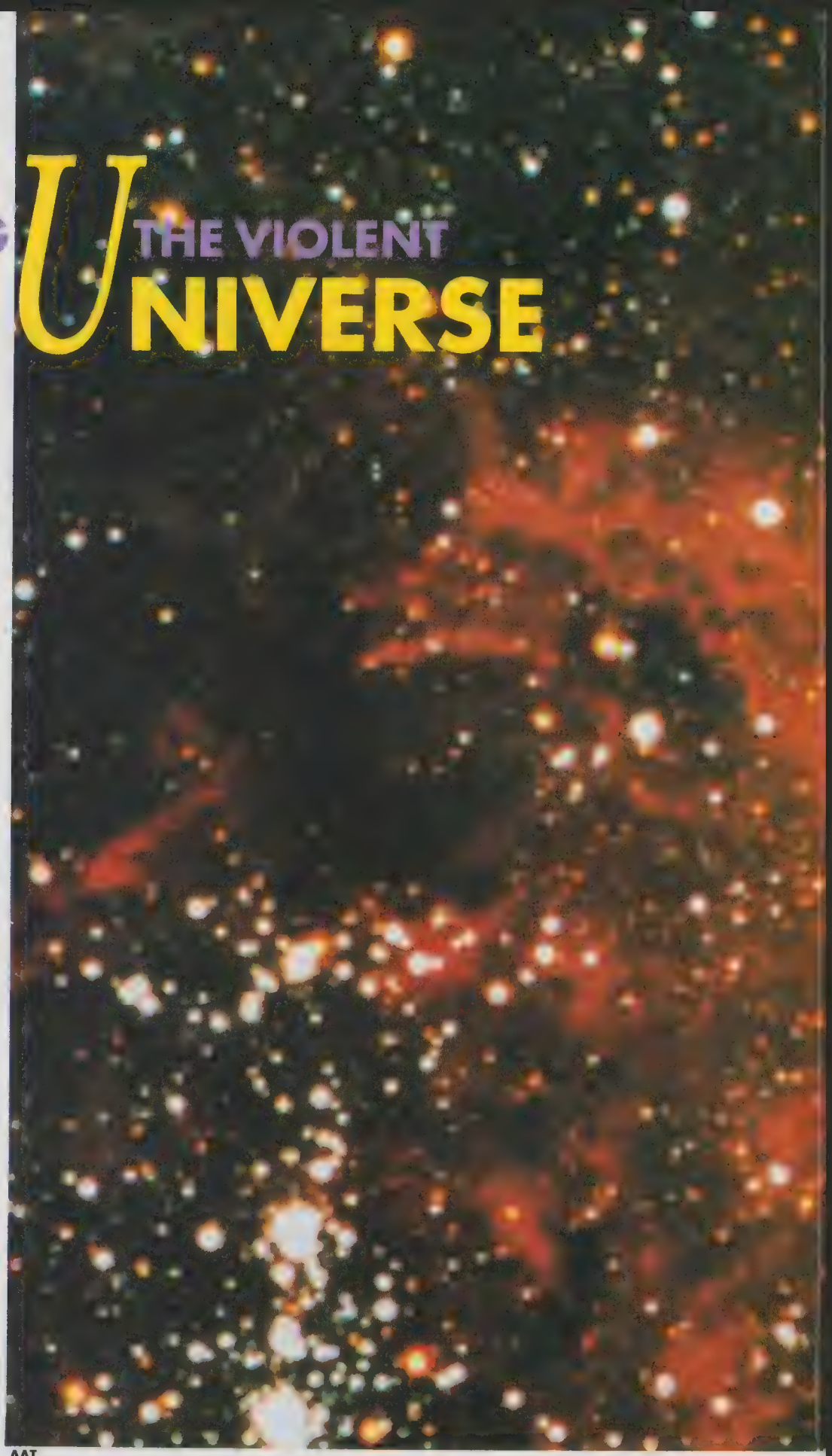


(Above) Figure 6: The effect of an unsharp mask on the visibility of the Trapezium stars in Orion. In a print from the original negative (a), many faint stars are hidden in the glare from the brighter ones. After copying the negative through an unsharp mask (b), the nebulosity and glare is removed, revealing faint stars, (c).

SCANNING THE VIOLENT UNIVERSE

by Kate Doolan

NASA'S ORBITING GAMMA RAY OBSERVATORY HAS SOME INTERESTING RESULTS



AAT

Supernova 1987a in the Large Magallenic Cloud — six months after the optical brightening reached us, it became a source of gamma rays.

GAMMA RAYS ARE INTERESTING to astronomers. They are very energetic, so it is assumed that gamma radiation would be the result of massive explosions, perhaps from supernovae, pulsars, quasars and black holes. Astronomers like such objects, because they are extreme states of matter — very hot, very dense, very fast — which it is impossible to re-create in a laboratory. It's in such places that the secrets of nature are revealed.

However, the atmosphere is opaque to gamma rays, so studying them is extremely difficult. In fact, gamma ray astronomy needs to be done above the atmosphere. That is the justification for the 16-tonne, US$615 million, Compton Observatory, which has been orbiting the Earth at around 450km for the past year, with its instruments scanning the heavens for bursts of gamma radiation.

Already the results are surprising the world's astrophysicists, and causing them to revise their theories about the structure and development of the universe.

In the first 35 years of the space age, space-based observatories and telescopes have increased our knowledge of the universe greatly. One of the largest contributors to this increase in knowledge has been the US National Aeronautics and Space Administration, (NASA). It is planning to continue into the next century in the same tradition with the great observatories program.

The great observatories program has been built to study the universe across the electromagnetic spectrum. The first observatory, the much maligned Hubble Space Telescope, was launched by the space shuttle in April 1990. Its response is centred on visible light with some response in the infrared and ultraviolet.

Both the Advanced X-ray Astrophysics Facility, which will study the X-ray spectrum and the Space Infrared Telescope Facility which will study the infrared spectrum, are expected to be launched later this decade.

Other observatories which are not part of the great observatories program but which will be tied in, include the European Solar Optical Telescope, the Extreme Ultra Violet Explorer and the ROSAT observatory.

But the latest addition to the fleet is Compton, previously known as the Gamma Ray Observatory, (GRO). It is very much part of the great observatories program.

Astronomers have been waiting for coverage of this part of the spectrum for ages. Before the launch of GRO, astronomers used sounding rockets, balloons and satellite-borne instruments to get small samples of gamma ray activity.

The role of Compton is to probe the energetic events that emit a large amount of gamma rays. One such example was the 1987 supernova which took place in the Magellanic Cloud. Six months later astronomers detected gamma ray emissions from the supernova debris. The findings of the observations showed that supernovae are a significant source of gamma rays in the universe.

Another area where Compton has revolutionised science is in the study of gamma ray bursters. Typically occurring about once a day and lasting from a few thousandths of a second to a few hundred seconds, these bursts of intense gamma rays seem to be the result of some powerful explosion somewhere in the universe — but where? Astronomers can't see what these things are coming from, since they don't last long enough to be captured in a telescope. It isn't even clear whether the bursts originate close by or in the depth of the universe.

Observations from Compton do not solve the problem, but they do provide some tantalising clues, as well as destroying some cherished theories.

The front running theory was that the bursters were the result of matter from a companion star falling onto the surface of a neutron star. (*See the article on the* Death of a Star *for an explanation of neutron stars.*) Theorists have speculated that when material falls onto the star it triggers some sort of crustal col-

Opposite, the Compton Gamma Ray Observatory hangs on the end of the space shuttle manipulator arm.

lapse, which gives of a prodigious burst of energy, so causing the gamma rays.

If this is the case one would expect gamma rays to have the same distribution in the sky as neutron stars — clustered in the plane of the Galaxy and possibly more pronounced towards the centre. But it turns out on the strength of Compton results, that gamma ray bursters are distributed randomly around the sky.

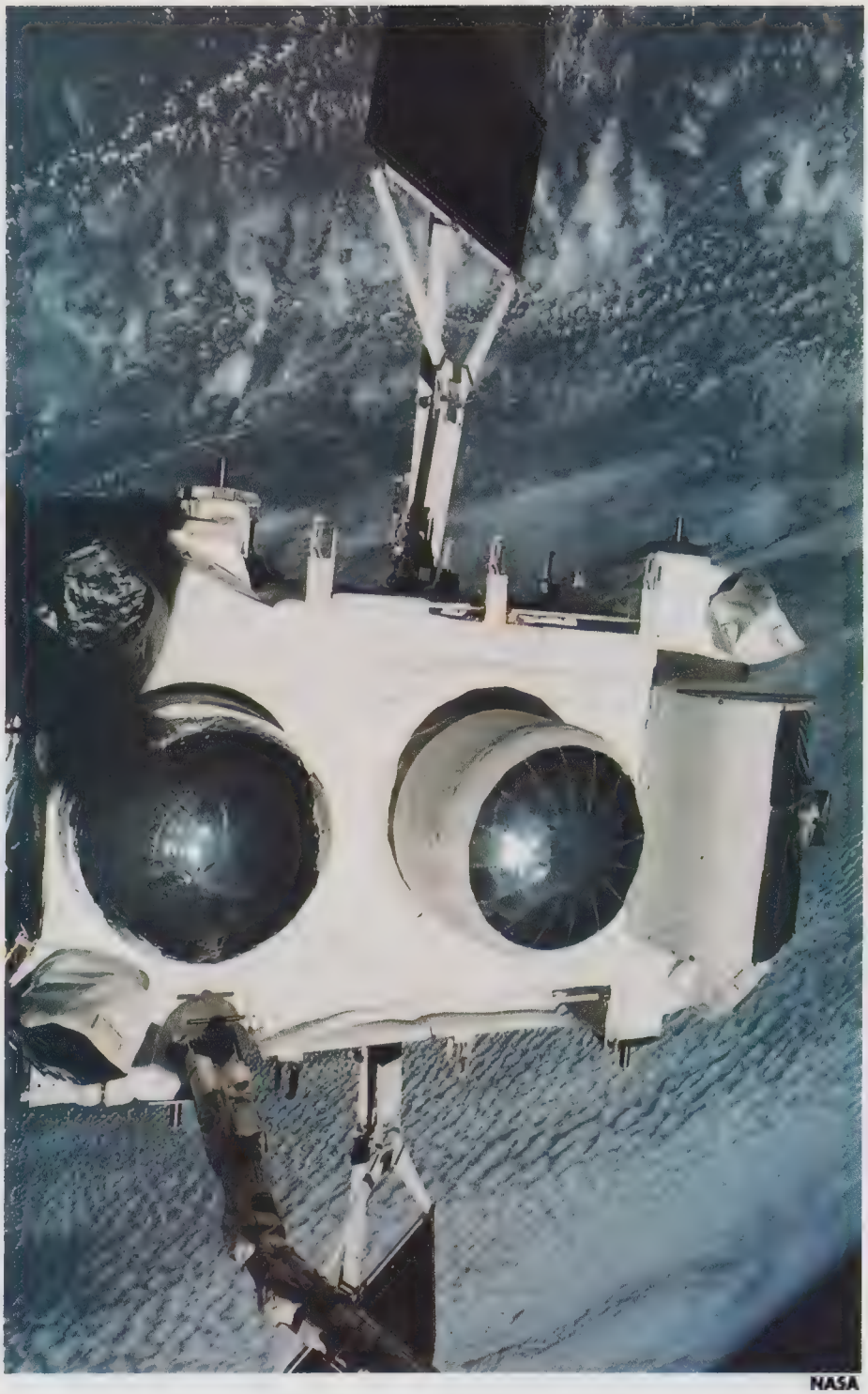
As in all good science, however, this just creates more problems than it solves. It tuns out that not only are the bursters distributed all over the place, there is also a strong cut off in their signal strength. This is curious. On the average, one would expect close objects to appear more luminous than distant ones. A cut off in signals below a certain strength implies there is some bound on the distribution. If there was not, one would get a steady decline in signal strength, corresponding to distant bursters.

This doesn't happen. There seem to be two types of solution. Either the bursters are quite close to us, say buried just beyond the orbit of Pluto. But if they are created close by, why do we not detect the sources at any other wavelength? The other option is that they are at the furthermost edges of the universe. But this means prodigious energy requirements, much more extreme than those of a quasar.

The answer will no doubt require much observation and thought.

There are four instruments on GRO, which are basically telescopes for seeing gamma radiation. They observe gamma rays by monitoring flashes of visible light known as scintillations, which occur when gamma rays strike the detectors built into the instruments. GRO's scientific instruments are the largest and the most sensitive ever flown into space to detect gamma rays.

The gamma rays emitted from celestial objects span a large range of energies. The most energetic gamma rays that will be studied by GRO have energies up to one million times greater than the weakest. This is a greater range



NASA

of energy than is spanned by optical telescopes, and as yet no single instrument has been invented that can detect gamma rays throughout this range. GRO's four instruments together span the range from approximately 20,000 to 30 billion electron volts, (eV).

The Burst and Transient Source Experiment (BATSE), was developed to monitor large segments of the sky for the detection and measurement of short, intense bursts and other transient sources of gamma rays. BATSE comprises eight identical detectors, with one placed at each corner of the spacecraft to give a wide field of view. BATSE operates in the low energy part of the gamma ray range (20,000 to 2 million eV), in which bursts are expected. Once a burst is detected by BATSE, it signals

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the other instruments to study the source in more detail. BATSE was developed at Marshall Space Flight centre in Alabama.

The Oriented Scintillation Spectrometer Experiment (OSSE), which was designed by the US Navy Research Laboratory in Washington, DC, detects nuclear-line radiation and emissions associated with low-energy gamma ray sources, (100,000 million eV). OSSE is especially sensitive to the spectral signature of radio-active elements, which enables the instrument to study supernovae and novae — where it is believed heavy elements are created. OSSE will also provide details on gamma ray emissions from neutron stars, quasars, pulsars and black holes.

The Imaging Compton Telescope (COMPTEL), was developed as an international venture between the European Space Agency, Germany, The Netherlands and United States. It has been designed to observe moderate gamma ray energies, (1 to 30 million eV). Although COMPTEL does not have a wider field of view than BATSE, it can locate gamma ray sources and one of its main roles will be to compile a map of the sky as seen in the moderate gamma rays.

Another international venture is the Energetic Gamma ray Experiment Telescope (EGRET) developed by the United States and Germany. EGRET's role is to search the universe for high energy gamma rays, to complement the map produced by COMPTEL. EGRET will also monitor gamma ray emissions from pulsars.

Compton was the first payload for 1991 launched by the space shuttle. Atlantis lifted off from Kennedy Space Centre in Florida on 5th April, with a crew of five astronauts aboard. The crew spent their first two days in orbit checking out GRO and its systems.

INSIDE COMPTON

COMPTON IS THE HEAVIEST payload ever launched by a space shuttle. It is also the largest robot spacecraft that NASA has constructed. Weighing in at a hefty 15,875 kilograms, the GRO is nearly double the weight of the Hubble Space Telescope. It measures nine metres long and is approximately 4.5 metres in diameter. When deployed, its two solar panels measure 21 metres from end to end.

GRO contains a self-contained propulsion system that allows ground-based controllers to keep the spacecraft at its correct altitude. This system also provides thrust for orbit changes, orbit maintenance, attitude control and if necessary a controlled re-entry into the Earth's atmosphere.

Four propellant tanks hold 1900 kilograms of hydrazine fuel. GRO has four 45 kilogram thrusters and isolation valves and also has two 2.2 kilogram thrusters for attitude control. The fuel tanks have been designed so that space-walking astronauts can replace them, but no mission to do so has been allocated for the next four years — although that can be altered if the spacecraft is in any danger of falling to Earth.

The role of GRO's Altitude Control and Determination (ACAD) subsystem is to point its instruments to selected gamma ray sources and to supply altitude information for data processing. The ACAD subsystem is a three-axis system which comprises standard NASA spacecraft components; sensors in the ACAD subsystem point the spacecraft and act as actuators for vehicle orientation.

The primary sensors are known as Fixed Head Star Trackers and the Inertial Reference Unit. The star trackers relay data to GRO's onboard computers regarding the location of the spacecraft based on the known positions of previously programmed guide stars. The Inertial Reference Unit relays altitude and position information based on the inertia, working in a similar manner to a gyroscope.

Communications and Data Handling (CADH) systems for GRO are based on similar designs used for both the Solar Maximum Satellite and the Landsat systems. Using modules, repair or replacement of damaged components can be performed easily by space-walking astronauts. An example of this was in 1984, when astronauts repaired the Solar Maximum Satellite — which was eventually boosted into a higher orbit where it operated until 1990.

The CADH subsystem comprises the CADH module, a 152 centimetre high-gain antenna, two omnidirectional low-gain antennae, as well as a radio frequency combiner to interface the CADH with the antennae.

Also included on the CADH are two Tracking and Data Relay Satellite Systems (TDRSS) transponders for both incoming and outgoing transmissions to TDRSS, and for command and telemetry transmissions to the space shuttle during deployment sequences. Two standard tape recorders are included for data storage to record data for later playback to scientists. Data dumps take place every two orbits, at a rate of 512 kilobytes per second via the high-gain S-band antenna and the TDRSS. GRO also has a clock that converts spacecraft time into universal time.

GRO's two solar power panels are accordion style, rigid arrays which are deployed by motor driven booms. The total available power is 2000 watts. During the time when the spacecraft is in darkness, it is powered by NiCad batteries. Power can also be provided by external sources, mainly through ground-based testing and in the shuttle payload bay.

Three kinds of temperature-regulating heaters are used on GRO, each having duplicate heater elements and thermostats. Operational heater circuits are sufficient for orbital operations. 'Make-up' heaters replace the power of an instrument when it is turned off in orbit. Whilst GRO is in the shuttle payload bay auxiliary heaters are used to maintain temperature.

CONTROLLING COMPTON

INSTRUCTIONS ARE sent to GRO by ground-based controllers located in the GRO Payload Operation Control Centre (POCC), at Goddard Space Flight Centre, in Maryland. This is the focal point for all pre-mission and orbital operations.

The POCC is a part of the Multi-satellite Control Centre at Goddard that provides mission scheduling, telemetry data acquisition, tracking and command, and any processing required for down-linked data.

The engineering and experiment data of the spacecraft will be processed at the POCC and the Packet Processor Data Capture Facility, (PACOR). Real-time data will be received by the POCC as well as telemetry from the NASA Tracking and Data Satellite Network. The PACOR will also receive real-time and playback data in parallel with the POCC and, after recording time order and quality checking, transmit science data packets to the four instrument sites, using either an electronic mail system or magnetic computer tape.

The Mission Operations Room is responsible for mission control and is operated on a 24-hour a day roster. This will provide flight dynamics and communication support through the use of an extensive array of computers, television and microprocessors.

On day three of the flight, astronaut Linda Godwin grappled the GRO with the shuttle's Remote Manipulator System (RMS), arm and lifted the spacecraft out of the payload bay. With GRO securely attached to the arm, the solar panels were unfurled and they immediately started to provide power to the spacecraft. The deployment of the spacecraft then proceeded normally, until the high-gain antenna would not budge from its stowed position.

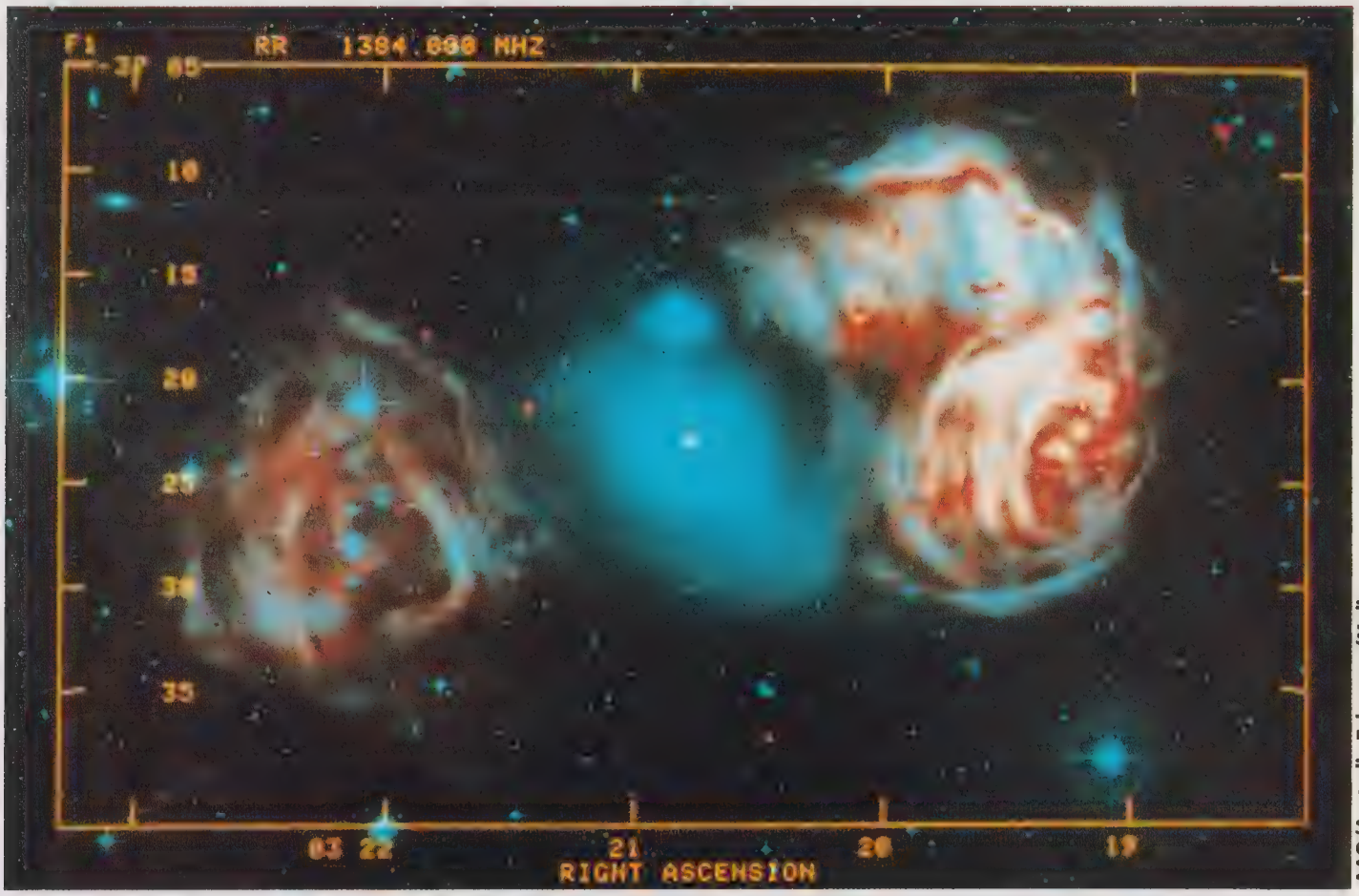
Attempts to free the antenna by ground controllers failed, as did attempts by using the shuttle's control thrusters and by shaking the spacecraft with the arm. The last option was to send out astronauts Jay Apt and Jerry Ross on a an emergency spacewalk to try and free the antenna. Seventeen minutes after the spacewalk started, Ross (who was tethered to the shuttle), used the highly non-technical means of pushing the antenna to free it. Later investigation found that the thermal insulation shaken by launch vibration had snagged on GRO, keeping the antenna stuck. For another four hours, Ross and Apt stayed outside to ensure that no further problems developed.

Following the remainder of the deployment checkout, GRO was released into a 535-kilometre high orbit.

The Atlantis then pulled away, but remained within distance in case anything went wrong. For the remainder of the STS 37 mission, the two astronauts, Ross and Apt made another spacewalk and the whole crew conducted science experiments — including taking some spectacular photographs of war-ravaged Kuwait. ◐

The true scale of the Gamma Ray Observatory is revealed in this shot in the shuttle cargo bay. Astronaut Jerry Apt, seen here clinging to the port side cargo door, had to manually open the antenna. Notice the massive solar panels stretching off to the right.

NASA



AAO/Australia Telescope/Malin

Optical and radio images superimposed. The blue haze, and the surrounding starfield, is a conventional optical image. The red and white is a map of radio emission.

Ask ten people to think for a moment about astronomy, and you'll probably find that nine out of the ten will conjure up images of beautiful stars, majestic galaxies and perhaps a shiny white dome atop a mountain.

Certainly, such an icon of modern astronomy can be seen by travelling the inland route from Melbourne to Brisbane. I refer to the domes of the telescopes on Siding Spring mountain, just west of Coonabarabran. They are clearly visible some thirty kilometres away from sections of the Newell Highway.

Such domes are characteristic of optical observatories which astronomers use to examine the light of stars and galaxies. Domes protect the telescope from the weather. The instrument, an optical telescope, is housed inside the dome and is extremely sensitive to light. For this reason, it is operated only at night-time, permitting no bright lights in its surroundings. Optical telescopes range in size from the small ones which can be bought in a shop, to the big ones used by astronomers to see stars, planets and galaxies.

Adverse weather, such as fog and rain, or even just thin, high cloud through which stars are clearly visible to the naked eye, force an optical telescope to close down. This is why sites are chosen very carefully. Even the Moon conspires to brighten the sky for about two weeks each month and makes most observations impossible.

Many people imagine that this is what astronomy is all about, but, as I write, it is daytime and raining at the Australia Telescope's Parkes Observatory, yet the Parkes telescope is operating. The reason is that this is a radio, not an optical, telescope. It operates night and day, rain or shine, naked to the weather. The characteristic of many radio telescopes, and of Parkes in particular, is the huge dish-shaped metal structure. It is 64 metres in diameter and you can see it from two kilometres away, again from the Newell Highway. Though the dish can be affected by the wind, it doesn't need a dome. The science is called radio astronomy and, in the early days of astronomical research, radio astronomy was considered the poor cousin of its optical counterpart. This is no longer the case.

By Rick Twardy

Think of astronomy as a story. Optical astronomy has, so far, provided about every third word; the gist is apparent but more details are needed. Radio astronomy then prov-ides about every other third word, and the story becomes much clearer. Early work with the Parkes radio telescope revealed insights into our own galaxy that could not be learned from optical observat-ions. Of course this works the other way, where optical astronomy often fills in the missing words from enigmatic radio messages.

The Parkes radio telescope has been operating for thirty-one years. It is one big measuring instrument, big enough to walk around inside. Its purp-ose is to measure radio energy, as waves of each frequency come from different parts of the sky. It's the astronomers' job to understand why.

The first clue that there might be more to the story than the optical telescopes could tell came in 1932 from an American telephone engineer who discovered that one cause of static on long-distance radio links was the Milky Way. He called this phenomenon "cosmic noise", hence the origin of the expression, "listening to the stars". However, it may surprise readers to learn that radio astronomers listen to the stars about as much as optical astronomers look at the stars; that is to say, they don't. So let's look at and compare how optical and radio tele-scopes work.

Each instrument must capture, detect and process energy for which it is suited. In a modern research optical telescope, a large mirror is aimed precisely at the designated target to gather light energy. The shape of the mirror is especially important. Properly done, it forces light waves from any one point in the sky to bounce, or reflect, off the mirror and meet again at a single point (the focus), a few metres above the mirror. This is critical.

At radio frequencies, wire mesh acts like a mirror. The shape of the Parkes dish, a paraboloid, reflects radio waves and "crowds them together", at a single focus that stands 27 metres above the dish. Here, the energy of the radio waves is absorbed by a wire. The micro-voltages so produced are magnified electronically to more easily managed strengths, for later processing. The device which absorbs and amplifies the signals is known as a receiver. Different receivers are used for different experi-ments on different sources for study. The principle, as with home radios, is to "tune in" to different frequencies. But, it is the computer that processes the electronic bits of data, not the astronomer.

Very sensitive parts of the receiver must be cooled to within a few degrees of absolute zero. This reduces the unavoidable electronic noise to a level which allows the signal to be discerned. In the same way, it is increasingly nec-essary for detecting devices in optical telescopes to be super-cooled, too.

Charged-coupled devices are replacing photography at the focus in optical telescopes. These CCDs are cooled by liquid nitrogen and operate well below a hundred degrees below zero. As detectors they are unsurpassed, sensitive enough in some cases to announce to observers the arrival of individual photons of light. The human eye has no role at this stage. Optical astronomers have not looked through a research instrument for decades. Indeed, astrophotography had replaced the human eye at the focus long before the arrival of CCDs. It brought the world spectacular images of, for example, the Andromeda Galaxy and the Horsehead Nebula.

Sir Isaac Newton observed the rainbow spectrum of white light over three hundred years ago. Optical

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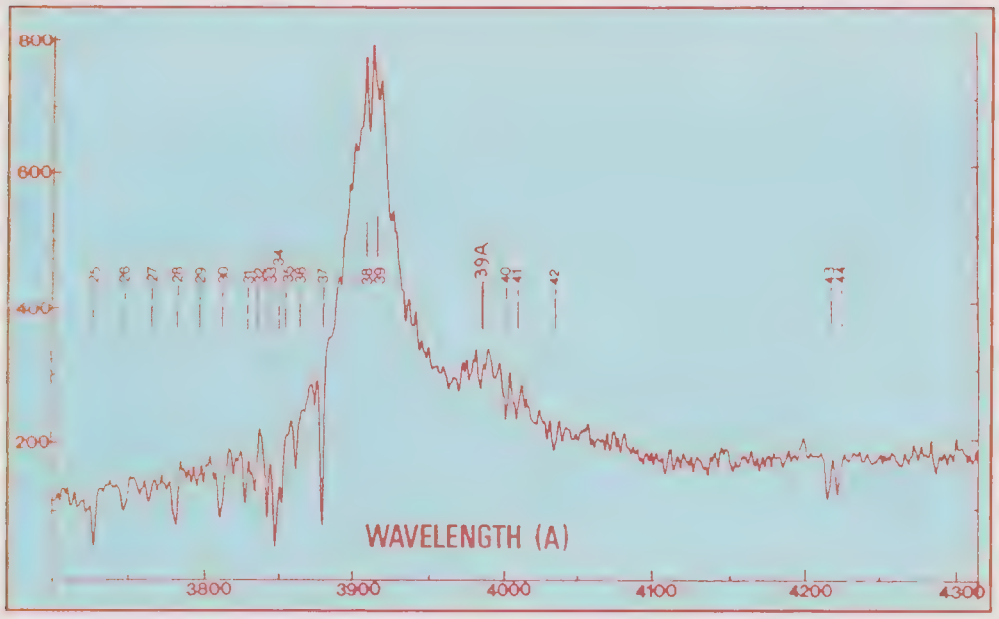
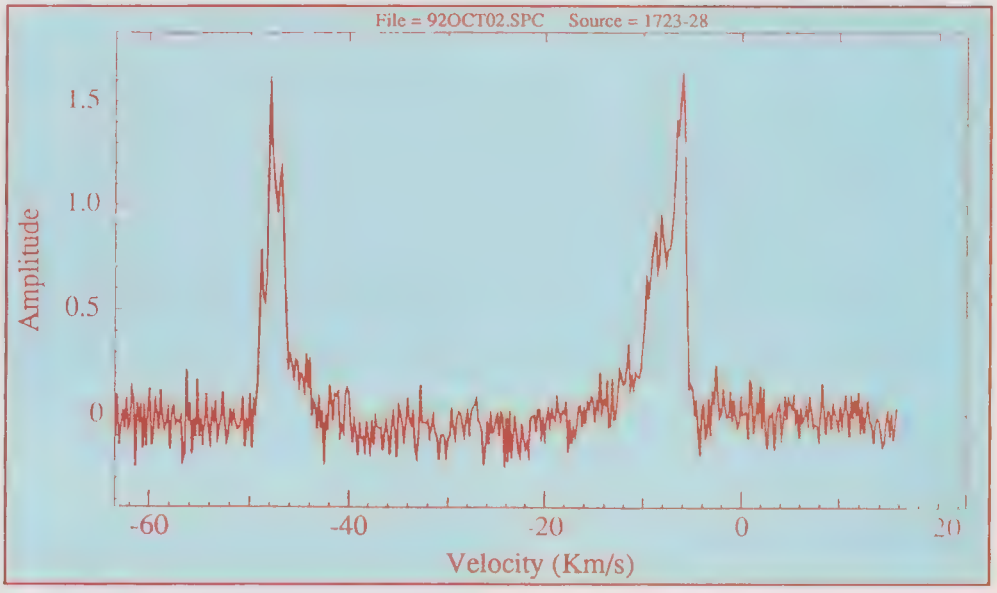
The radio dish at Parkes, NSW.



Diagrammatic arrangement of a radio telescope. In a radio telescope, it is often the case that the fine guidance for the telescope is provided by a Master Equatorial Unit, which, being small and light, can be locked onto a star with great accuracy. The big telescope assembly then follows the Main Equatorial Unit.

Both optical (left), and radio (below), images can be converted into a spectrum. This can reveal much about the atomic processes that underlie the radiation coming from the source, as well as its motion relative to us.



astronomers realised the significance of stellar spectra about seventy years ago. That changed the focus of research from mere star-measuring and cataloguing to understanding stars. This branch of astrophysics is based on examining the colour of stars for clues. The technique, known as spectroscopy, separates a mixture of energy into its components, allowing the temperature, composition, turbulence, and motions of the star or galaxy to be estimated. It was optical spectroscopy that showed that galaxies were moving apart, providing clues to the motions of galaxies and the idea of the "big bang". Radio spectroscopy has been possible for only about 30 years, and has produced identical conclusions.

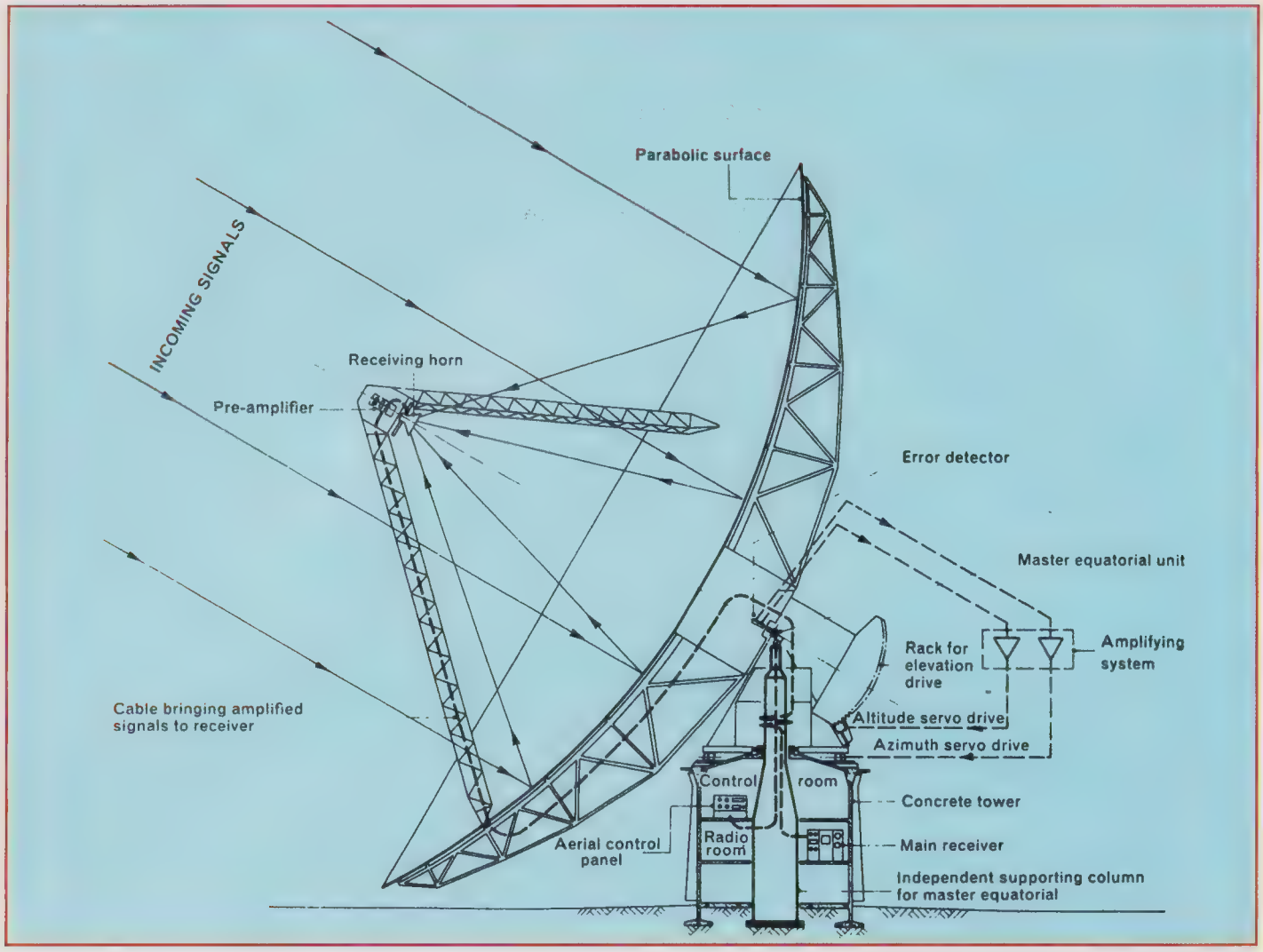
For many experiments at the Anglo-Australian Telescope, the largest of the telescopes at Siding Spring, optical fibres channel the light from each star in the view to be split into its component colours. At Parkes, such multi-beam spectroscopy has just become possible, though it is not done using optical fibres.

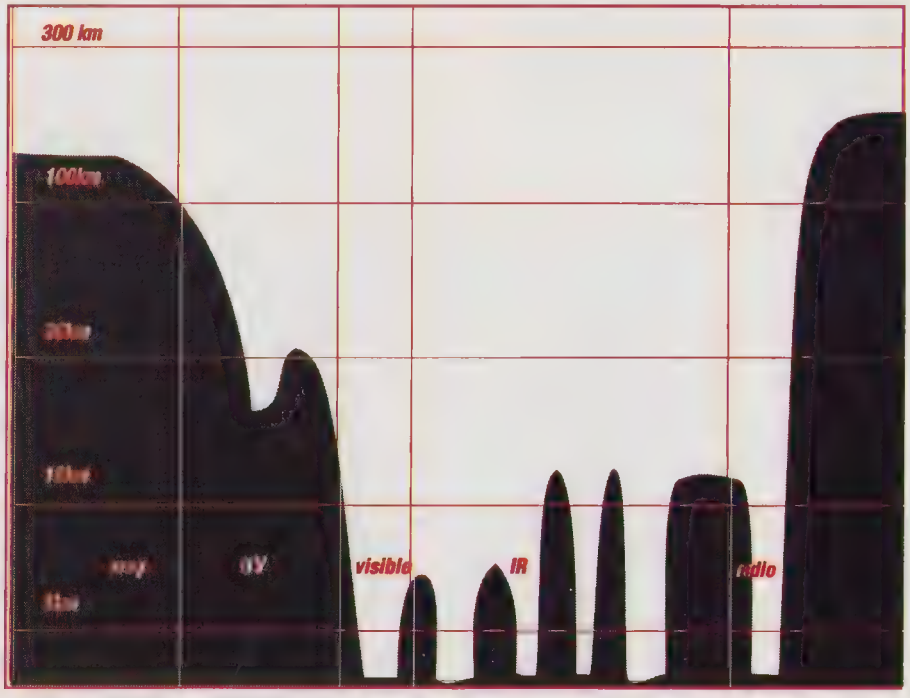
High technology has replaced the human eye and ear entirely. Computer recording and processing of signals are essential. Radio astronomy has always relied on electronic apparatus for recording and displaying results, and has always led the way in using computers to analyse data. The Hubble Space Telescope delivers optical results only if transformed by computer processing.

Today, the best radio "pictures" are put together by networks of radio antennas systematically scanning a small region of sky. Most look like computer-coloured maps, and they often are. Perhaps disappointingly, optical astronomers rarely publish their spectral results as colours. The human eye cannot distinguish sufficiently the subtle variations in colour; instead, each spectrum is converted to a graph. This graphical presentation of spectra makes results from both optical and radio observatories look very similar. So, have a look at a popular astronomy magazine. See the latest, and most colourful results from both optical and radio observatories.

I should say here that there are other kinds of astronomical research: for example, infra-red, ultra-violet, x-ray and gamma-ray. They all make influential contributions to the astronomy story. And one day there may be neutrino and gravitational-wave astronomy, too.

However, if you want to check out the difference between optical and radio astronomy, come to the Parkes Astronomy Education and Visitors





Centre at night in a group for some hands-on experience. We have two large optical telescopes you can look through and a baby radio telescope from which you can hear the "cosmic noise".

Rick Twardy is at the Australia Telescope National Facility, CSIRO Astronomy Education and Visitors Centre, PO Box 276, Parkes, NSW 2870.

The atmosphere is not clear at all wavelengths. In fact, we can see the sky only through a few small windows, one at the visible wavelengths, and the other at radio wavelengths. It is possible to make some infrared observations at very high altitude observatories. None are in Australia however.

Part of the Vela supernova remnant. These clouds of dust and gas were ejected from the star, which is off the picture to the right, and ar now mixing with the interstellar matter. One day this material will form another star, possibly some planets and who knows, maybe intelligent beings who can look at the sky and wonder what it all means

WHILE THEY LIVE, STARS ARE MUCH THE SAME. THE DIFFERENCE COMES WHEN THEY DIE. JON FAIRALL EXPLAINS.

THE DISCOVERY THAT the stars are not immortal has been one of the great discoveries of the twentieth century. It has reshaped cosmology, religion, how we view our place in the universe, and even how we view ourselves.

Until the beginning of the 17th century, people thought the universe was static — nothing was more immutable that the heavens. But in 1572 Tycho Brahe was able to show that the new star of that year — a supernova — actually belonged to the sphere of the stars. Then, with the publication of Newton's *Principia* in 1687, it was demonstrated that the motion of planets was governed by the same law of gravitation that applied on the Earth.

From such events a new school of thought arose, which held that the universe was governed by laws of physics which scientists could seek to understand. One law of particular interest was the conservation of energy, first formulated by Julius Meyer in 1842. One consequence of this law is the understanding that energy must be supplied from some source. On Earth, the ultimate energy source is the Sun.

But what was the source of the Sun's energy? Even more important: how long would it continue to be supplied? The Victorians loved a good disaster, and the suggestion that the Sun might go out next year — or next week, occupied many an over-fevered imagination.

The problem was finally solved with the development of atomic theory in the 1920s. This showed that the power source in the Sun was the transmutation of hydrogen into helium. It then took a very short time to build up

EATH OF A STAR

a model of stellar evolution which applied to all stars.

We see stars in a variety of states. Some are bright, others dim. Some are one colour, some another. By examining their spectra, we can tell that some are very much hotter than others. Yet the modern conception of a star is actually quite simple. It is a ball of gas in equilibrium, and all the variety we see in the sky can be accounted for simply on the basis of how much gas the star contains. (Well, almost. Some stars do vary in chemical composition, but that is a complexity we will ignore in this account.)

A star is in equilibrium. The implication here is that the star is not getting bigger or smaller, but staying essentially the same over time. This happens because the individual particles that make up the star are subject to two balanced but opposing forces — gravity, which tries to squeeze all the particles of the star into a smaller and smaller space, and radiation and heat pressure from the centre of the star, which tries to push the particles outwards.

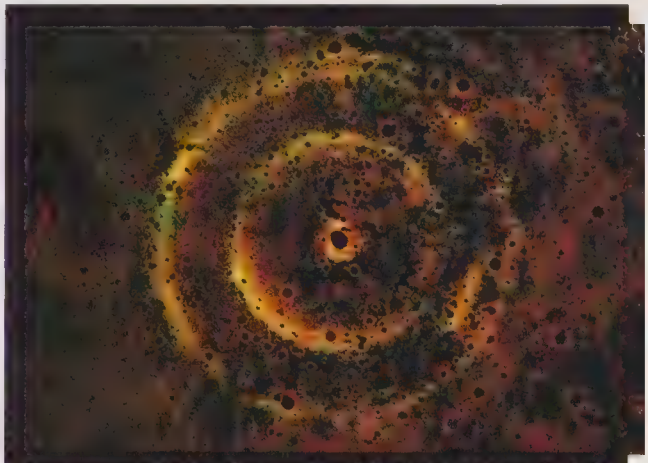
The inward gravitational force depends simply on the amount of gas in the star. The more gas, the more intense the force, and the more gas will be squeezed together in the centre of the star. As we shall see, this can lead to bizarre effects.

The outward force is radiation, produced by the atomic processes happening in the centre of the star. If these are few, the outward pressure will be slight and the star will contract. If the reactions are vigorous, the pressure will be greater and the star will expand.

These two forces are far from independent of each other. Atomic reactions occur in the centre of the star precisely because the gas is pulled together by gravitation. Individual atoms are forced closer and closer together until nuclear fusion — in which hydrogen atoms fuse to make helium atoms — takes place. The more matter piled onto the star the greater the rate at which this occurs.

Eventually, the hydrogen is all consumed. What happens then? The key is mass, the amount of gas in the star. Astronomers use the mass of the Sun — about 315 trillion trillion tonnes — as a convenient measure. We can dismiss an object with a mass less than 0.08 from our calculations — it never gets hot enough to start nuclear reactions. It will probably liberate heat due to contraction for many years, before settling into black quietude. Stars between 0.08 and 0.5 solar masses also lead pretty sedate lives. Their cores are dense enough to fuse hydrogen into helium but slowly, over the eons, their nuclear fuel is used up. They may be able to augment their nuclear energy by contracting slightly, but eventually, they too become cold and dark.

We call such objects black dwarfs, Since they are black, and radiate nothing, it is hardly surprising we have not seen any. However, several brown dwarfs — small cool stars — have been spotted which seem to be slipping quietly into extinction.



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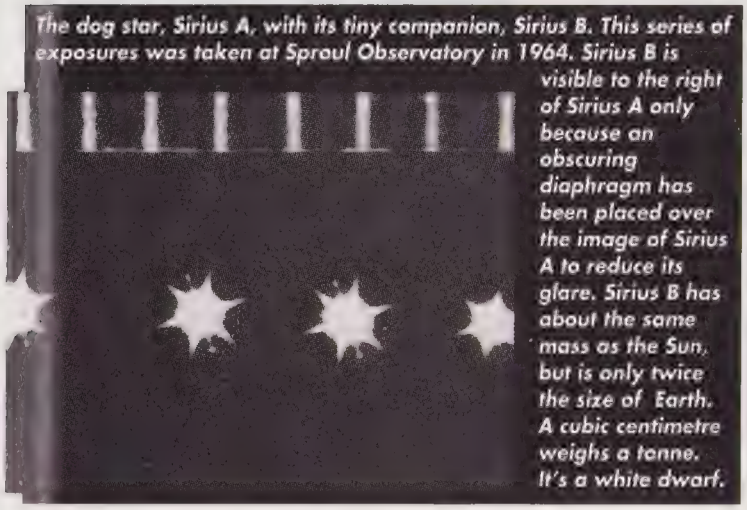
Supernovae 1987a. The star Sanduleak-69 202 exploded in 1987 and confirmed much of what scientists believed about supernovae. A burst of neutrinos from the supernova was the first received from outside the solar system.

This is not very exciting — you will be pleased to know that stars bigger than 0.08 solar masses end their lives in far more spectacular fashion. They bloat up to become red giants.

As such a star ages, it accumulates helium in its core. Since this is just the ash of the hydrogen reaction, it has no source of radiation to push outwards, and it begins to contract under its own weight. Its temperature increases. This in turn heats the hydrogen layers above it. As the total energy output increases, the star expands. This process continues for some time — the Helium core becoming smaller and hotter, and the hydrogen above it expanding as it is heated. The radius can reach a value fifty times that of the original star.

Paradoxically, although the amount of energy coming out of the star has increased, as has the radius, the surface of the star is now cooler than it



The dog star, Sirius A, with its tiny companion, Sirius B. This series of exposures was taken at Sproul Observatory in 1964. Sirius B is visible to the right of Sirius A only because an obscuring diaphragm has been placed over the image of Sirius A to reduce its glare. Sirius B has about the same mass as the Sun, but is only twice the size of Earth. A cubic centimetre weighs a tonne. It's a white dwarf.

►►►

The Ring Nebula, a planetary in Lyra. This star is shedding mass on its way to becoming a white dwarf. The striking colours occur because the light travels different distances inside the nebula before being absorbed by the gas, and thus heating it. When the gas re-radiates it does so at frequencies that depend on the temperature.

Hale Observatories

was previously. This is because the energy liberated per unit area of the surface is now reduced. So much so, in fact, that it assumes the characteristic red colour that gives red giants their name.

If the star is massive enough, the helium core may be squeezed enough so that another round of nuclear reactions can take place. Helium atoms will fuse to make carbon and oxygen. Now a carbon core is created, with helium reacting in a ring around it, and then hydrogen on the outside. This process can continue — carbon fusing into heavier elements, which in turn fuse into heavier elements, so that the star looks like an onion. If the star is sufficiently massive, the process will continue creating layer on layer, each layer composed of heavier elements, until it creates an iron core — the final product of fusion.

How far the process goes will be set by the mass of the star. The reactions will stop when there is insufficient mass to squeeze the core enough to begin the next cycle of reactions. So as the star ages, increasingly its energy will be supplied from the upper layers. It may destablilise, varying in brightness and radius, but the trend is all downwards.

As the amount of energy available contracts, so does the star. In the end, gravity wins. But this poses an interesting question. In the absence of thermonuclear reactions, what sets the size of a stellar corpse?

Think about ordinary matter — this magazine, your thumb, the rocks under your feet. The atoms that make up these object are composed of electrons bound to nuclei by electrostatic forces. These forces control how much material can be gathered in any given volume — the density — and set it at a gram per cubic centimetre on average.

However, above about the mass of the planet Jupiter, say one thousandth the mass of the Sun, gravity takes over as the dominant force regulating density. It's useful to imagine a Jupiter sized planet, and ask what happens as we pile matter onto it. Unsurprisingly, it gets denser and denser. Eventually, the pressure gets so great that the electrostatic forces break down. Electrons fly about unconnected to protons or neutrons, providing the repulsive force. Physicists call such material electron degenerate.

However, it turns out that if you increase the mass beyond the Chandrasekhar limit — 1.4 solar masses, even the electron pressure is insufficient to withstand gravitational pressure. The electrons are effectively pushed inside the nuclei of the atoms, and it is the repulsive forces of these neutrons that set the density. The density of a neutron star is truly fantastic. A star like the Sun would occupy only 15km, and a cubic centimetre of its stuff would weight over a billion tonnes. But this is not quite the end of the story. As one piles more mass onto a star, one reaches the Landau-Oppenheimer-Volkoff limit at three times the mass of the Sun. At this pressure, even nuclear forces are overcome. There is no known physical force that can withstand the overwhelming forces of gravity. All the matter in the star congregates at a point source, or singularity.

These are all fabulously dense states of matter, predicted theoretically by scientists. Do they exist in nature, and how do they fit into the story of stellar evolution?

In fact, electron degenerate stars were first observed in 1910, well before the atom theory had been worked out. The star 40 Eridani B was found to have a high surface temperature, but to be extremely faint. This could only be explained if it was extremely small. For a while, astronomers were puzzled by the fantastic density this implied. They called it a white dwarf, and have now discovered several hundred.

NASA

sands or millions of times the mass of the Sun, b that black holes like this, but smaller, could also remains of a single star.

It was during the 1920s that astronomers were able to identify White Dwarves as stars in a state of electron degeneracy. True to theory, they are all less than 1.4 solar masses. What's more, scientists now believe the white dwarf is the fate of all normal stars. As the star slowly collapses, it sheds its out layers, often forming spectacular planetary nebula. All that's left is the degenerate core.

But the white dwarf can not be the fate of all stars. Chandrasekhar's

limit says that there is no stable white dwarf over 1.4 solar masses, and stars are known to exist up to 100 solar masses. But a neutron star would be small, and therefore faint, so it was not obvious how they could be identified.

Astronomers had to wait until 1968. Then radio astronomers at Cambridge University found a star that emitted a radio pulse (hence pulsar), every 1.33730113 seconds. After little green men were eliminated, it turned out that the only scientific model that worked was for a very compact, spinning body with a tilted magnetic field. The only way to get the necessary degree of compactness was via a neutron star.

Astronomers also believe they have identified physical objects with the singularity beyond three solar masses. These are black holes. The idea of a black hole is not new. The 18th century astronomer Laplace reasoned that since the velocity needed to leave a planet or star — its escape velocity — depended on the mass of the planet or star, there must be some mass so big that light itself could not escape.

Black holes ain't so black. This image from the Hubble Space Telescope shows a giant disk of gas, 300 light years across, fuelling a black hole. The disk is tipped about 60 degrees to us, so that we can see right into the hub. The disc is at the core of NGC 4261, a galaxy in the Virgo cluster, probably 45 million light years away. To support such a structure, the black hole would need to be big, possibly thou- there is strong evidence created from the

Our modern view of black holes stems from Albert Einstein's General Theory of Relativity, which argued that gravitation deforms and curves the structure of space. One can think of a gravitating body as being in a well. It requires energy to climb out. But some wells are so deep that no amount of energy is enough. This is the black hole.

Nevertheless, the physical properties of black holes are so bizarre that for many years, astronomers refused to accept they could really exist. It took a while to realise that black hole is a most inaccurate description of what these objects really are. As matter circles close to a black hole, it obeys ordinary laws of physics which say that it will speed up. It does so, but in the extreme conditions of the black hole, it speeds up to close to the speed of light. This results in a massive conversion of matter to energy. In fact, it's the most effective way possible to create energy. Far from being black, black holes are incredibly bright.

This is why scientists have become interested in black holes again. They are needed to explain all sorts of really energetic phenomena, like quasars — galaxies at the end of the universe that shine with the light of a thousand conventional galaxies, or like x-ray stars.

From this account, you might conclude that black holes and neutron stars are very common, at least as common as massive stars. In fact, they are probably quite rare, because it turns out that massive stars are very good at getting rid of mass.

All stars convert mass to energy to shine. Remember that the Sun is fuelled by atomic fusion, in which mass is converted into energy according to Einstein's famous equation, $E=Mc^2$.

In the case of the Sun, this mass loss is about a ten trillionth part of its total mass per year. This is insignificant, even if the Sun burns for 10 billion years, but for red giants, the rate of energy flow out of the star is so large that it must convert an appreciable proportion of its mass to radiation. In fact, a star of 30 solar masses probably uses 24 of them before its red giant stage is over.

More spectacularly, astronomers now believe that most pulsars and neutron stars are the remnant of very massive stars that blow up — supernovae. In some cases, nothing is left after the explosion. In others, a small dense object, possibly only 10 per cent of the original mass, may remain.

Exactly why supernovae explode is still something of a mystery. According to one of the favourite theories, however, the progenitor is supposedly an old star with an onion-like structure and an iron core. The core is very hot and dense — hotter than 5 billion degrees. At this temperature nuclear reactions start to produce many neutrinos. Neutrinos are particles which contribute nothing to the radiation push of the star, since they rarely interact with matter.

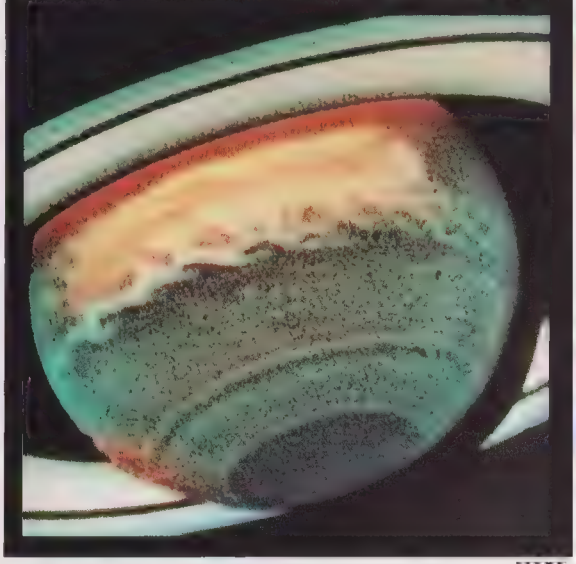
The result is that the radiation/gravitation equilibrium of the star is destroyed. The star begins to contract, heating the core even more. This in turn increases the production of neutrinos and reduces the radiation push. The core collapses into either a neutron star or a black hole, depending on its mass.

The sudden, massive increase in temperature of the core causes the outer layers of the star to ignite. In a few seconds, enough nuclear fuel to last a billion years will be consumed.

Supernovae are important to us. They are the only known mechanism where nature can create elements heavier than lead, like titanium or uranium. Also, they are the most efficient way of spreading star-stuff back into the void, so that it may be used for a new round of star making.

All the atoms that make up our world, including those inside your body, were made in stars, and given back to the void by a supernova. We are all indeed star-stuff. ◐

The planet Saturn seen from the Hubble Space Telescope with a new white spot prominent. The solar system's large gas planets, Saturn and Jupiter, are about as big as an object can get with all its atoms in normal form. Any bigger and the intense pressure at the centre forces atomic reactions to begin. Both planets currently generate about 30 per cent of their energy output internally. The rest is just reflected from the Sun.



NASA

How to make money out of space and astronomy — or how

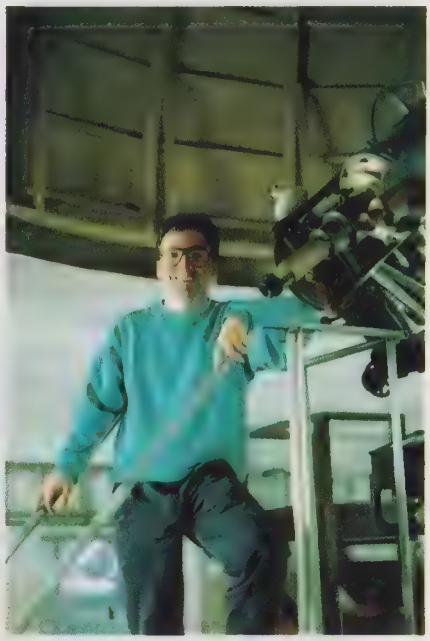
Six years ago, a small group of enterprising individuals sat down to develop an idea for a new magazine. There was nothing very unusual about that; new magazines were cropping up all the time in the late 1980s, and surely one more couldn't make that much of a difference.

But this one could and would. For this was to be Australia's first and only regular magazine about astronomy, the scientific study of the stars. In fact, it was to be the only one produced especially for the whole Southern Hemisphere of this planet. This was quite significant, for all the other astronomy magazines around at the time came from the United States, and weren't really appropriate for Australian skies.

The magazine was called *Southern Astronomy*, and the enterprising individuals were Jonathan Nally, Lyle Rumble, and his daughter, Melissa Rumble.

"This was always a magazine with a difference," says Jonathan Nally, the magazine's editor. "Most magazines are just money making ventures, but we had higher ambitions for *Southern Astronomy*." While they certainly approached it from a business point of view, for the *Southern Astronomy* team it was also a labour of love, particularly for its editor. "As an amateur astronomer, I had known for a long while that Australia desperately needed an astronomy magazine of its own, but no-one had actually done anything about it. Whilst the US magazines were very good, people were becoming fed up with not being able to read about things which they could see in their own night sky. So, we decided that the time was right for Australia to have a magazine of its own."

The two principals of the business, Jonathan Nally and Lyle Rumble, brought complementary skills and experiences to the venture. Jonathan's background in astronomy and his contacts in that field provided for the content of the magazine, and Lyle's background in printing and graphic arts covered the production side of the business.



Tim Homes.

Would you buy a magazine from this man? The photo shows Jonathan Nally in the dome of Carter Observatory, New Zealand's National Observatory during a recent marketing and fact finding tour.

Working in the very cramped conditions of Lyle's graphic arts premises, they put together a design for the magazine and collected a team of expert authors. "We were very fortunate to attract a top class team of contributors right from the start. They were all specialists in their fields, and each had been itching for a chance to participate in a project such as this," said Nally.

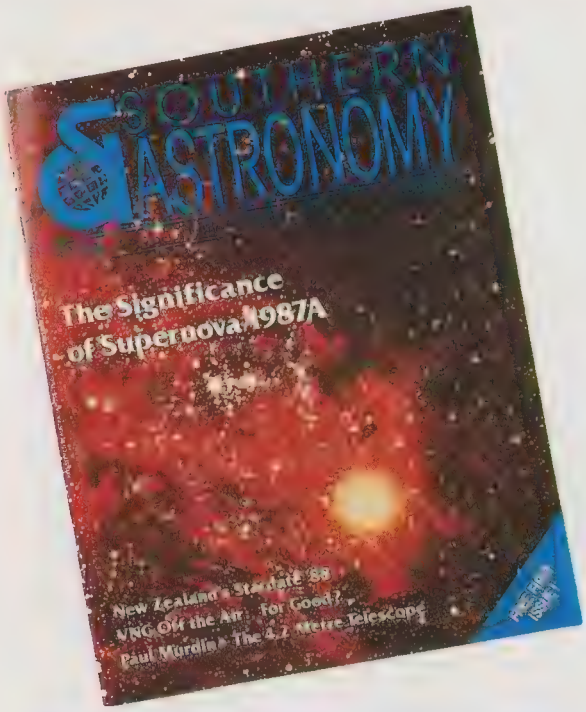
The team of contributors, who covered all the main areas of amateur astronomical observations and skills, were supplemented by calling on the services of Australia's professional astronomical community. "Just as with the amateurs, the professionals were tickled pink that someone had bitten the bullet and produced a magazine that could promote their research to the wider community," he said.

Since those first days, *Southern Astronomy* has grown in leaps and bounds. The initial readership of around 1,000 has grown to over 15,000 — a remarkable achievement, and one of which they are justifiably proud. "It's been a lot of hard work, and we've had to make many sacrifices to make this work," says Lyle Rumble. "The general economic conditions did not help either."

Despite the hardships, the magazine is prospering and has even recently undergone a slight change of image. In order to appeal to a wider audience, and to be more prominently displayed in newsagencies, a decision was taken in the middle of 1992 to change the name of the magazine. From November last year, *Southern Astronomy* became *Sky & Space* magazine.

"Our research indicated that some potential readers were turned off by the word 'astronomy' in the title — they thought it sounded too scientific. As well, many potential readers use the word 'space' when they really mean 'astronomy'. We also decided to increase the space exploration content — the Voyager missions and so on. Finally, believe it or not, a major factor in the name change was to combat the problem of *Southern Astronomy* being placed in the astrology section in newsagencies! It really happened.

to broke with a smile on your face.



The very first issue of Southern Astronomy magazine, April/May 1988.

to keep it. "We don't want to join the queue of companies going overseas for their printing," says Lyle Rumble.

In these grim economic times it is good to see a local product doing so well. Australians should be proud of *Sky & Space* magazine, and of the support it provides to astronomy, an important part of Australian science.

Sky & Space magazine can be bought at most newsagencies or readers can subscribe direct. A single issue costs five dollars; a year's subscription (six issues), is $30. Subscriptions can be ordered from *Sky & Space* Magazine, Subscriptions Department, PO Box 374, Bondi Junction, NSW, 2022; phone (02) 387 6666. ◐

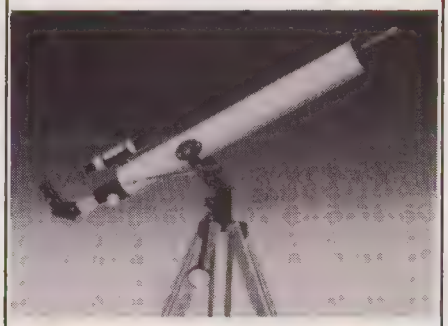
"The new name more accurately reflects the interests of our readers: the night sky above us, and beyond that, space," Jon says.

Over the past five years, the magazine has grown in size too, from 40 pages to 64, and from completely black-and-white content to a mixture of colour and black-and-white. "This year we will add more pages and lots more colour," says Nally. "In fact, at the moment we're finding it hard to squeeze everything in!"

Perhaps the most remarkable thing about *Sky & Space* is that, unlike many start-up magazines, it is a completely home grown product. All production and printing is done in Sydney, and that's the way they intend

The November/December 1992 issue of the new-look Sky & Space magazine. Inside, it's the same magazine, only more so!

FROM THIS...
MEADE SKYROVER MK III



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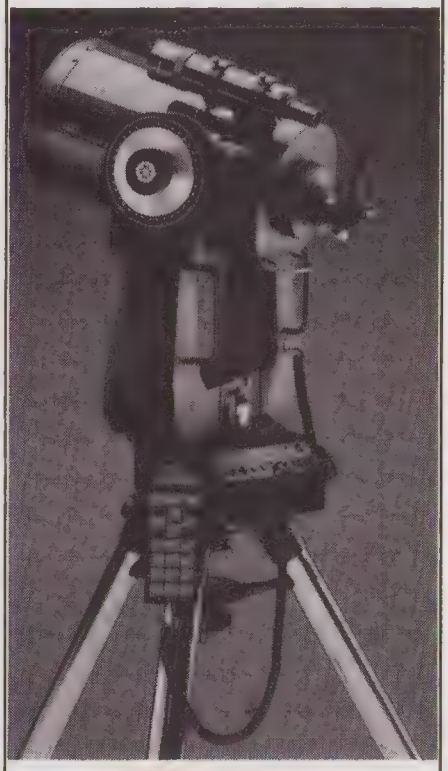

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TRAINING FOR A CA

By Robin

Astronomy has always been one of the more popular sciences. To go out to watch the universe march across the sky at night costs nothing. But to become a professional astronomer requires years of study and access to advanced scientific instruments.

The conditions of employment for astronomers are such that all but the most dedicated drop out. For a start, there are very few positions for professional astronomers. When they become available, they are fiercely contested by the best scientific achievers.

The basic education for an astronomer requires eight years at university. The first four will be spend on an honours degree in science, (or a pass and a masters). Then four more years, on average, will be spent on a PhD.

Then, once the tyro astronomer has completed formal study, a move overseas is often necessary. This is either to pursue special interests not available in Australia, or because there are no positions available locally.

In fact, overseas travel is one of the essentials of the job. It is important to attend conferences and workshops overseas, to exchange information and discuss new results. You will also need to use overseas telescopes to augment or complete observations begun at home.

However, an astronomical institution employs more than just research scientists. There are support staff with skills in engineering, computing, photography, editing, publishing, librarianship, metal trades and carpentry. People with skills in these fields, as well as an interest in astronomy, have the opportunity to compete for these as they become available.

Once a position in a particular field is gained there may be opportunities to progress to another field after further part-time study. For instance, its quite possible to be promoted from metal trades to engineering, or from computer programming to astronomical data reduction.

Students interested in astronomy should consider doing their work experience in year 10 or 11 at one of the institutions listed on this page. There you can see how a scientist really works. At the very least, you may learn some of the skills required to survive in the job. They don't all have to do with the more obvious educational requirements.

If this is impractical, these places occasionally have open days to allow visitors to see laboratories. As a third option, such institutions will often provide scientists to talk to school gatherings or at career days at high schools.

For those of you still interested, you will need plenty of luck, as well as stamina, motivation and imagination to make something of the information coming your way.

We wish you the best of luck! ◐

Dr Allan Vaughan, Senior Lecturer in Physics at Macquarie University, at the university's 250mm telescope. It is used for the study of variable stars. When a larger instrument is used, the university has a working relationship with the Australia Telescope.

WORK EXPERIENCE

These institutions often take work-experience students:—

OPTICAL OBSERVATORIES

Anglo Australian Observatory
(02) 868 1666

Mt Stromlo Observatory (06) 249 0230

Siding Springs Observatory (068) 426 221

RADIO TELESCOPES

Australia Telescope National Facility
(02) 868 0222

CSIRO Division of Radio Physics
(02) 868 0222

Parkes Radio Telescope (068) 623 677

*Otrupcek**

STUDIES FOR A CAREER IN ASTRONOMY

AT UNIVERSITY ENTRANCE LEVEL students require the following subjects:—

English — mandatory;
Mathematics — mandatory;
Physics — if skipped in senior high school, must be taken in first year university;
Chemistry — if skipped in senior high school, must be taken in first year university;
Computer Science - very useful.

UNDERGRADUATE DEGREE
First year — physics, mathematics, chemistry and computer science;
Second Year — begin to specialise, and leave out either chemistry or computer science;
Third year — physics and mathematics;
Fourth Year — honours in physics or mathematics;
An alternative is a degree in electronic engineering, (although this usually takes six years).

POST GRADUATE COURSES
A PhD requires 4—5 years of slave labour at one of the graduate schools mentioned in another side panel in this article. Most of them have a collaborative supervisory agreement with the Australia Telescope.

GRADUATE SCHOOLS IN AUSTRALASIA

ACT
Australian National University, Institute of Advanced Study
Optical astronomy at Mt. Stromlo or Siding Springs; radio astronomy with the Australia Telescope.
Australian Defence Force Academy, Physics Dept.
Infra-red studies.

NSW:
Sydney University, School of Physics
Astronomy, astrophysics and theoretical astrophysics.
University of NSW, School of Physics
Astrophysics and optics.
Macquarie University, School of Maths and Physics
With the Australia Telescope.
University of Western Sydney, Dept of Physics
With the Australia Telescope.
University of Wollongong, Dept. of Physics
Astronomy and astrophysics.

NZ
Auckland University, Physics Dept.
Astrophysics including gamma-ray astronomy.
University of Canterbury, Physics Dept.
Optical Astronomy at Mt John Observatory.
University of Wellington, Dept. of Physics
Optical astronomy at Mt John Observatory

Qld
University of Queensland, Dept. of Physics
Astrophysics, cosmology

SA
University of Adelaide,
Dept. of Mathematical Physics

Tas
University of Tasmania, Dept. of Physics

Vic
Monash University, Dept. of physics, Dept. of Maths or Dept. of Chemistry
University of Melbourne, School of Physics
Astrophysics.

WA
University of Western Australia, Dept of Physics
VLBI radio astronomy, plasma physics.

*Robina Otrupcek is an astronomer working at the Australian National Telescope Facility.

Interested in Astronomy? A catalogue of some astronomical and space-related places to visit in Australia by Martin George.*

There are many places in Australia whose connection with astronomy or space makes them well worth a visit. The more significant ones are listed here, but local astronomical societies and space groups are worth contacting as some conduct public nights and visit schools.

For teachers wishing to take a class, advance bookings are essential in most cases and it is advisable to book early to avoid disappointment. Some places — in particular the planetaria, in which an audience sits under a domed ceiling in a darkened room — have an age limit, as they are not suitable for very young children. Admission prices and opening times, where given, are correct at time of publication but are subject to change.

AUSTRALIAN CAPITAL TERRITORY

Tidbinbilla Space Tracking Station.
The tracking station is located about 40km south west of Canberra.
Group bookings: telephone (06) 201 7800.
Open: 9am — 5pm every day.
Admission: free.

The visitors' centre contains many displays relating to space tracking. From the centre, visitors can obtain a view of the actual antennae.

NEW SOUTH WALES

The Australia Telescope — Narrabri Array.
Paul Wild Observatory, Narrabri.
Enquiries: telephone (067) 904 000 on weekdays between 8am and 4pm.
Admission: free.

Tours are welcome; large groups are advised to make a booking. This is the heart of the most advanced radio telescope in the southern hemisphere. Radio emissions collected by a number of dishes are combined to obtain the performance of a single very large radio telescope. The visitors' centre contains an excellent display which explains the operation of the telescope.

Gilgandra Observatory, Gilgandra.
Bookings and charging information: write to John Estens, PO Box 81, Gilgandra, NSW 2827; phone (068) 472 646.

The owner has spent many years as an amateur astronomer and now welcomes visitors to his observatory.

Grove Creek Observatory.
The observatory is located 62km south of Bathurst near the Abercrombie Caves.
Bookings: telephone Steven Williams on (02) 565 1438.
Admission: adults, $12, children, $6.

Proceeds from the admissions charges contribute to research at the observatory. The observatory contains three telescopes that are available to the public for booked groups only. A tour of the observatory includes an informative lecture by an experienced astronomer, and a look into deep space through the telescopes. Camping facilities are available at the caves; alternatively, arrangements can be made for the group to stay at a nearby motel.

John Tebbutt Observatory.
The observatory is located in Palmer Street, Windsor.
Bookings and charging information: telephone (045) 772 485.

This real working observatory conducts day visits, which include a guided tour of the observatory and the original telescope used by John Tebbutt (who appears on the Australian $100 note), and night visits which — weather permitting — include observation through telescopes. It also has a small planetarium. Other attractions include Haddon's House of Clocks nearby.

Parkes Observatory (Australia Telescope National Facility).
The observatory is located 20 minutes' drive north of Parkes.
Bookings: telephone (068) 623 677.
Admission: free.
Open: 361 days a year from 8:30 am to 4:30 pm.

The world-renowned Parkes radio telescope has an astronomy education and visitors' centre. The centre features displays and interactive exhibits, and a superb audio-visual

**Martin George is at the Launceston Planetarium.*

The Anglo Australian Telescope is a typical large equatorial instrument. At 4 metres, it is the largest telescope in Australia, and the fourth largest in the world.

entitled *The Invisible Universe*. With the experienced and friendly staff on hand to help any curious seekers of knowledge, you will find your visit really excellent! Information, astronomy material and souvenirs are available. Allow at least an hour for the visit; school visits are a speciality.

Siding Spring Observatory.

The observatory is located near Coonabarabran.
Bookings and charging: telephone (068) 426 239.
Open: seven days a week for day visits only.
Admission: adults, $5.00, pensioners and children, $3.00, family, $12.00.

Visitors can see Australia's largest optical telescope — the 3.9-metre diameter Anglo-Australian Telescope. The viewing gallery offers excellent views of the instrument, and there is a fine display about modern astronomical research.

Stardome

A travelling planetarium for schools in the Sydney area. Greg will bring his inflatable planetarium to your school. There is a minimum requirement of 100 children for the day. Each session runs for about 45 minutes. The facility caters for kindergarten to year 12.
Bookings: telephone Greg Hayward on (02) 389 4728.
Admission: $3 per head.

Sydney Observatory

The observatory is located on Observatory Hill, not far from the city centre, and close to the historic Rocks area, just west of the southern approach to the Sydney Harbour Bridge.
Bookings and enquiries: telephone (02) 217 0485.
Admission: for evening sessions: adults, $5, children, $2.

The Observatory concentrates on public education and, as

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SYDNEY OBSERVATORY

When he arrived in Sydney in 1856, William Scott's first job was to construct his observatory. He supervised the construction of a permanent building on the site of Dawes' original observatory, and it remained probably the busiest observatory in Australia until the 1920s, when light pollution from the city began to reduce its effectiveness. The opening of the Sydney Harbour Bridge, with its lights shining straight down the barrel of the telescope, was the coup de grace bringing serious astronomy to an end.

Sydney Observatory, the oldest in Australia, remained open until 1973, recording among other things, time and tides. It is now administered by the Powerhouse Museum, Sydney's science museum, and is open to the public for tours and demonstrations.

►►► Continued from page 61

well as accepting groups for daytime visits, conducts evening sessions six nights per week. Weather permitting, this includes observation through telescopes.

QUEENSLAND

Sir Thomas Brisbane Planetarium.

The Planetarium is located in the Mt. Coot-tha Botanic Gardens, Mt. Coot-tha Road, in Toowong, Brisbane.

Bookings and enquiries: telephone (07) 377 8896 from noon to 7pm, Wednesday to Sunday; bookings for school sessions for each year open the previous November.

Admission: adults, $6.50, pensioner/student concession, $5.00, children under 15, $3.00. Group rates are available.

A number of fine displays are also in the building.

SOUTH AUSTRALIA

Adelaide Planetarium

The Planetarium is located at the Levels Campus of the University of South Australia, at Pooraka.

Bookings and other information: telephone Rita Mielnik at the University on (08) 302 3138. The Planetarium is open to booked groups only.

Admission: adults, $4.00, children and pensioners, $3.00. Groups of up to 40 can be accommodated.

The Heights Observatory

The observatory, which houses a 30cm diameter telescope, is run by the Astronomical Society of South Australia and is located in the city area. It is open to the public one evening per month, on the Friday closest to the first quarter moon.

Information: telephone the Society on (08) 338 1231.

Admission: adults, $2.00, children under 15, $1.00. No bookings are required for these Friday evening sessions, but large groups may be accommodated on separate dates.

Stockport Observatory

This observatory is also run by the Astronomical Society of South Australia and contains 51cm and 38cm telescopes. It is open to the public one evening per month on the Saturday closest to the first quarter moon, (ie the night after The Heights Observatory is open). Other info is the same as for The Heights.

TASMANIA

Launceston Planetarium

The Launceston Planetarium lies within the Queen Victoria Museum in Wellington Street, Launceston.

Public showing times: 2pm and 3pm Tuesday to Saturday inclusive, with shows also on Mondays during government school holidays. No bookings are required for public shows.

For group bookings and other information: telephone (003) 316 777 between 9am and 5pm weekdays.

Admission: adults, $3.00, children under 15 or students in booked groups, $2.00.

The adjoining Telecom Space Gallery contains many interesting and informative displays, including a live television view of the Sun showing its sunspots, flares and other phenomena, and a working cosmic ray detector that counts the tiny particles as they pass through the building!

VICTORIA

Melbourne Observatory.

The Old Melbourne Observatory is located a few minutes' drive south of the city centre.

Enquiries regarding group or private visits should be directed to the Melbourne Planetarium on (03) 669 9942. Informative two-hour sessions at the observatory, from 8pm to 10pm, are conducted by members of the Astronomical Society of Victoria.

For enquiries regarding dates of open nights, for which no bookings are required, telephone the above number.

Melbourne Planetarium

The H. V. McKay Melbourne Planetarium is located within the Museum of Victoria in Swanston Street, Melbourne, close to the city centre.

Public showing times: Wednesday and Thursday at 2pm; Friday at 2pm and 8pm; public and school holidays at 11am 1pm, 2pm, 3pm and 4pm; and weekends at 1pm, 2pm, 3pm and 4pm.

For group bookings and other information: telephone (03) 669 9866 or (03) 669 9854.

Admission: adults, $8.00, children under 15 and concession, $4.00; children in school groups, $4.50. These prices include admission to the Museum of Victoria. Family tickets are available, and reduced rates apply on Friday evenings.

This was Australia's first planetarium, established in 1965. The Museum of Victoria provides other educational attractions.

WESTERN AUSTRALIA

Perth Observatory

The Perth Observatory is located in Walnut Road in Bickley.

For information and group bookings: telephone (09) 293 8255 from Monday to Friday during office hours. Weekday and night-time tours, for which bookings are required, are conducted one week per month. In addition, there is a public daytime tour every Sunday for which no bookings are required.

Enquiries regarding current charges should be made to the Observatory.

This is a real working observatory, where valuable research is done. Educational displays are to be seen, which include instruments from the old Observatory.

RNI Bank Space Dome

The Space Dome — a travelling planetarium — is based at the Sci Tech Discovery centre in Perth.

For bookings and other information: telephone Graham McMahon on (09) 481 6295.

During the year the Space Dome travels to various locations in Western Australia. The Sci Tech Discovery Centre itself is an impressive interactive science centre, well worth a visit. ◐

GLOSSARY

This is a list of some of the terms you might find of use in reading about astronomy: —

A: Short for Angstrom. A unit of measure equal to 10^{10} metres. It is often used in astronomy as it is a convenient unit in which to measure the wavelength of light. Red light has a wavelength of about 7000A.

AAT: Anglo-Australian Telescope. The 4m aperture instrument run by the Anglo Australia Observatory on Siding Springs Mountain in Northern NSW. It is the biggest telescope in Australia, and the fourth largest in the world.

Albedo: The albedo of a planet is the ratio of the sunlight it receives to the sunlight it reflects.

Astronomical Unit: The mean Earth—Sun distance, taken as 149.598 x 10^9 metres.

Australia Telescope: Very large radio interferometer in northern NSW. The compact array consists of six dishes at the Paul Wild Observatory, Narrabri. The extended array includes dishes at Siding Springs, Parkes and Tidbinbilla in the ACT.

Big Bang: The putative primordial state of the universe was a singularity in which everything was concentrated. The expansion of the universe began when the 'cosmic egg' exploded.

Black Hole: A concentration of matter with an escape velocity of the speed of light, formed from supernova explosions, the collapse of galactic centres and possibly in the fireball of the big bang.

BL Lac object: Named after prototype BL Lactertae, they are probably close active galaxies. They are distinguished by rapid variation in the intensity of radiation at radio, infrared and optical frequencies, no strong emission lines, rapid variation in polarisation, (qv).

CSIRO: Commonwealth Scientific and Industrial Research Organisation. It is divided into divisions, of which the Department of Radio Physics at Epping in Sydney has the most impact on astronomy, through its interest in Radio Astronomy. CSIRO also runs the Australia Telescope National Facility. CSIRO's Office of Space Sciences and Applications (COSSA), in Canberra, has been involved in the construction and deployment of space-based instruments.

Celestial Pole: The pivot on which the night sky appears to turn. The long arm of the South Cross points directly at it. In the northern hemisphere it is marked by the bright star Polaris.

Cepheid variables: A type of variable star whose brightness variations are related to its intrinsic luminosity. It is thus possible to use them for estimating distance.

Chandrasekhar limit: About 1.44 solar masses. It is the upper mass of a White Dwarf, (qv). Stars more massive than this will collapse to form a neutron star, (qv).

Culmination: A celestial object culminates when it reaches its highest point in the sky, which occurs when it is due north.

Day:
(a) solar: the period between successive culminations (qv), of the Sun. It varies depending on the time of the year.
(b) sidereal: the period between culmination of a fixed star, ie the period of revolution Earth with respect to the distant stars.

Declination: A measure of position in the sky, corresponding to latitude on the surface of the Earth. It is measured in degrees North or South of the celestial equator

Deep Space Network: A NASA-operated system of very large antennae, situated in the US, Spain and at Tidbinbilla, ACT, for communication with space craft in deep space.

Doppler Effect: A wave phenomenon in which frequency appears to go up when an object approaches and reduces when it retreats. In cosmology, it manifests itself in the Red shift (qv), and in general, can be used to measure the movement of astronomical bodies towards or away from us. Astronomers do this by measuring the displacement of the Fraunhofer lines, (qv).

Dwarf Star: Small stars composed of collapsed matter in a state of degeneracy. The may be white, brown or black, depending on their temperature.

Ecliptic: The path of the sun through the sky against the background stars. It is divided into 12 constellations, hence the 12 signs of the zodiac beloved of astrologers.

Electromagnetic radiation: Radiation produced by electric and magnetic fields. It comes in different forms: —

radio: wavelengths longer than 0.005 m;
infra-red: wavelengths between 0.005 m and 4 x 10^7 m;
visible: wavelengths between 4 x 10^7 m and 8 x 10^7 m;
ultra-violet: wavelengths between 8 x 10^7 m and 10^8 m;
x-ray: wavelengths between 10^8 m and 10^{12} m;
gamma-ray: wavelengths shorter than 10^{12} m.

These numbers are approximate. The division between the different types of radiation is driven by the method of detection, rather than intrinsic differences between the types.

Ephemeris: A table of calculated positions for a celestial object.

Engineering notation: An economical way of expressing very large, or very small numbers.

1,000	= kilo (k),
1,000,000	= Mega (M),
1,000,000,000	= Giga (G,)
1,000,000,000,000	=Tera (T),

and: —

Fairall

The Deep Space Network, used by NASA to listen to space craft in deep space, operates this dish at Tidbinbilla outside Canberra.

0.001 = milli (m),
0.000001 = micro (u),
0.000000001 = nano (n),
0.000000000001 = pico (p),

so: —

6328 m = 6.328km,
32,000,000 lightyears = 32 Megalightyears (Mly),
1400,000,000,000 dollars = 1.4 Teradollars,

and: —

0.000000000018 Farads = 1.8 pF.

This is extremely useful way of expressing large numbers in text. See also next entry.

Exponential Notation: An economical way of expressing very large or small numbers.

900 = 9×10^2,
8,000 = 8×10^3,
70,000 = 7×10^4,
600,000 = 6×10^5,
5,000,000 = 5×10^6,
5,432,000 = 5.432×10^6,
4,000,000,000,000 = 4×10^{12},

also: —

0.9 = 9×10^{-1},
0.008 = 8×10^{-3},
0.000007 = 7×10^{-6},
0.00000006 = 6×10^{-9},
0.00000000005 = 5×10^{-12}.

This is an extremely useful way of working with big numbers, which astronomers do all the time. For instance, if you wanted to multiply 3 Mega litres by 4 Giga volts, just write $3 \times 10^6 \times 4 \times 10^9$. Now $3 \times 4 = 12$. Add exponents, so that $6 + 9 = 15$. Answer is 12×10^{15}. See also **Engineering notation**.

Fraunhofer lines: The lines in a stellar spectrum that betray the chemical composition of the source. Named after Fraunhofer, who discovered them in 1814.

Globular Cluster: A group of stars packed closely together. They are probably the finest sight available to the user of a small telescope.

Hertzpring-Russell Diagram: Any graph that matches some measure of stellar luminosity against some measure of temperature. Named by astronomers who first drew this graph. It revealed main sequence, giant and dwarf stars, which underlay current ideas on stellar evolution.

Light year: The distance travelled by light in one year. Equal to $9.46.05 \times 10^{15}$ metres.

Local Group: Our galaxy is gravitationally bound to a number of other galaxies. This is known as the local group. They do not take part in the general flight of the galaxies caused by the expansion of the universe. Most galaxies appear as members of Groups, or clusters.

►►►

There may also be groups of groups, imposing some sort of large scale structure on the universe. What this might be is unclear.

Luminosity: The intrinsic brightness of a star, or the actual amount of light emitted by a star. Often measured in Absolute Magnitude, which is the brightness the star would have at 10 parsecs, (qv).

M: Prefix given to nebula in the catalogue of Charles Messier, (published in 1787). The most famous object is M31, the Andromeda nebula.

Makarian Galaxy: Galaxy characterised by excess ultraviolet radiation.

Magnitude: A measure of the brightness of an object. The brightest star (Sirius), is of magnitude -1.45. The faintest visible stars with normal eyesight are of about 6th magnitude. The faintest visible through AAT (qv), class instruments are of about 21 magnitude. Each magnitude is about 2.5 times fainter than the one before it.

Missing Mass: The major problem of current cosmology. Studies of gravitation effects on galaxies shows the effect of mass that is not visible. Currently astronomers have no real idea in what form this mass may exist. Alternatives include planets, black holes and other forms of non-luminous cold matter, sub-atomic particles like neutrinos or other, undiscovered forms of matter.

Molongolo Cross: A radio interferometer run by the University of Sydney.

MSSO: Mt Stromlo and Siding Springs Observatories. The organisation responsible for running the observatories at Mt Stromlo and Siding Springs.

Neutrinos: A chargeless sub-atomic particle with little or no mass, (uncertain). Probably associated with the stellar collapse of a supernova, and may contain significant amount of missing mass, (qv).

Neutron star: A star formed of neutronium. This is a material in which the electron barrier between the molecules has been broken, so that neutrons rub shoulders. It is the densest state of matter known. Current theory dictates that all neutron stars are between 1.4 and 3 times the mass of the sun.

Oort Cloud: A giant reservoir of comets left over from the formation of the solar system. It may extend outwards about a light year from the sun.

Occulation: Occulation is said to occur when one astronomical body obscures another. In recent times it has been used to map planetary atmospheres and been responsible for the discovery of rings around Neptune and Uranus.

Parsec: One of the most popular measures of distance in astronomy. It is defined as the distance at which the stellar parallax is equal to one second of arc. It is equal to 30.546×10^{15} metres.

PKS: A prefix used to identify radio sources in the catalogue of radio sources compiled by the Parkes radio observatory.

Polarisation: Electromagnetic radiation (qv), consists of an electric field and a magnetic field perpendicular to each other and the direction of travel. Polarisation refers to the orientation of these fields. Radiation is plane polarised if the fields are all oriented in the same direction. If there is a phase difference, it is said to be circularly polarised.

Pulsar: A pulsating neutron star. They emit radio and optical energy in extremely regular pulses. Typically they issue several pulses a second. However, one has been observed with a frequency of nearly 2000 a second.

Quasar: QUAsi StellAR Objects: The most distant objects known, as measured on the basis of their red shift, (qv). Most modern models of a quasar picture galactic cores with a massive black hole (qv), surrounded by an accretion disc. They appear to be objects that were much more common in the early universe than now.

Red shift: As the universe expands, all the galaxies appear to be travelling away from us. This is revealed by a doppler shift (qv), in the spectrum towards the red end.

Right Ascension: A measure of position in the sky, corresponding to longitude on the surface of the Earth. It is measured Eastward along the celestial equator from the equinox. It is measured in degrees or in hours, (one hour = 15 degrees).

RR Lyre stars: A category of variable blue giant. All have periods less than 24 hours. Like Cepheids, they are reliable distance indicators.

Schwartzchild Radius: Critical radius, defined by the general theory of relativity beyond which a body becomes a black hole. So any body of mass M, having a radius less than $2GM/c^2$, where G is the Gravitational constant and c is the speed of light, is a black hole. The SR for the Earth is 90mm, and for the sun 2.5 km.

Seyfert Galaxy: A galaxy with an active nucleus, ie one that is very active and shows strong emission lines. Seyferts have many of the properties of Quasars(qv), and may be intermediate between quasars and normal galaxies.

Solar System: The sun, the nine planets that surround it and the moons associated with each of these, together with minor objects like asteroids and comets. It is generally held that the edge of the solar system is marked by the Oort cloud, (qv).

Star Types: Stars are grouped in spectral classes in order of descending temperatures O, B, A, F, G, K, and M. Students often remember this using the mnemonic, "Oh, Be A Fine Girl and Kiss Me".

Stellar Parallax: The movement of a star against more distant stars as a result of the movement of the observer, usually as the Earth moves about the sun.

Supernova: Explosion of a massive star at the end of its life. It leaves behind an expanding cloud of gas, plus an imploded core which may be a white dwarf, a neutron star or a black hole, depending on the mass of the original star.

SUSI: Sydney University Stellar Interferometer. The world's largest optical interferometer. It is situated at the Paul Wild Observatory, Narrabri.

Variable star: Stars that wax and wane in brightness. Many different types are known.

White Dwarf: A collapsed star less than 1.44 solar masses composed of electron degenerate material.

Wolf Rayet Stars: Class of very hot star that eject shells of gas with high velocity. ◐

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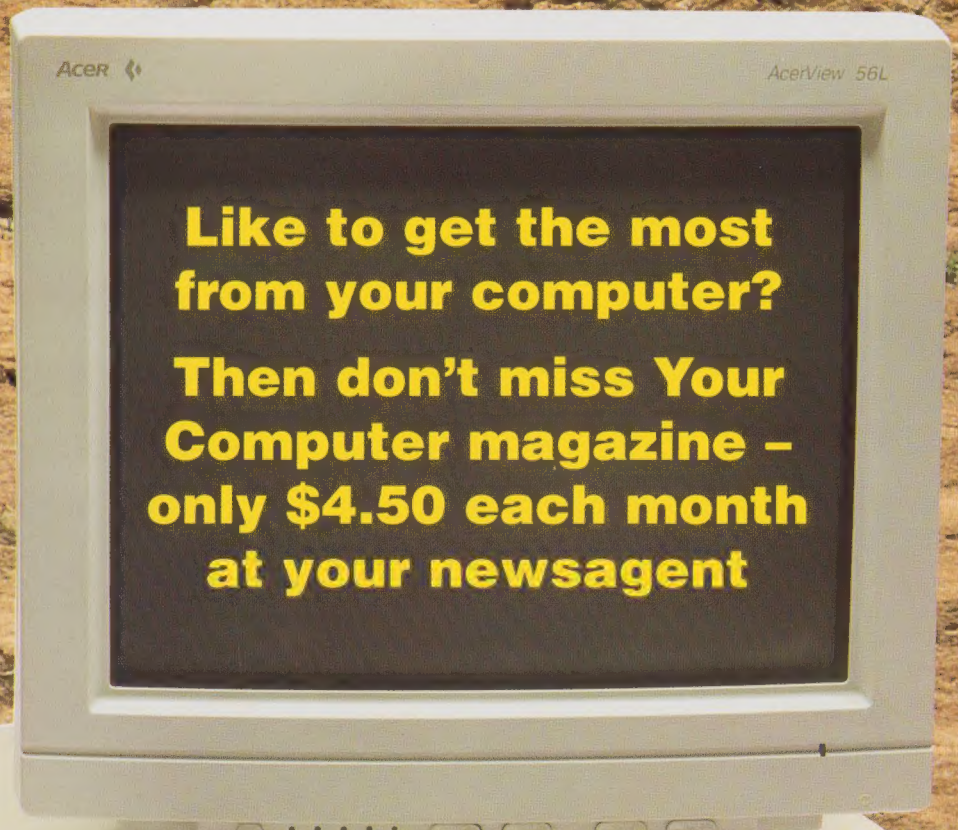
AUSTRALIAN PUBLICATION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Above: *Saturn and some of its moons.*
Below: *The surface of Mars.*
Main picture: *The Australia Telescope, NSW.*

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